Mosaic Radar - CREF   06/09/2004 1940Z   Lat: 50.5N - 22.5N Long: 126.0W - 65.0W

Cooperative Institute for Mesoscale Meteorological Studies

Cover figure - An example composite reflectivity image from the real time NMQ 3D mosaic (panel a) and two zoomed-in images for sub-regions (panels b and c). This example is from the very first one-kilometer mosaic product, using Level-II data from 130 radars in real-time. The reflectivity field is largely free of non-meteorological echoes such as ground clutter and clear air and biological returns. The mosaic field is consistent and seamless across umbrellas of different radars. The zoomed-in images show detailed structure of storms in smaller regions. For more on this project, see **NSSL2 – Quantitative Precipitation Estimation and Segregation using Multiple Sensors – *National Mosaic and Multi-Sensor QPE (NMQ)***, by Jian Zhang, Wenwu Xia, Shunxin Wang, Carrie Langston, Yuxin Qin, and Beth Clarke, under research theme ***Doppler Weather Radar Research and Development***.

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COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES
THE UNIVERSITY OF OKLAHOMA

Annual Report of Research Progress under Cooperative Agreement NA17RJ1227
During Fiscal Year 2004

Peter J. Lamb, Director
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INTRODUCTION

General Description of CIMMS

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) was established in 1978 as a cooperative program between the National Oceanic and Atmospheric Administration (NOAA) and the University of Oklahoma (OU). CIMMS provides a mechanism to link the scientific and technical resources of OU and NOAA to create a center of research excellence in mesoscale meteorology, regional climate studies, and related subject areas. CIMMS-supported scientists and students conduct research in mesoscale dynamics, radar research, development, and analysis, atmospheric electricity, severe storms, cloud microphysics, and boundary layer studies, with increasing emphasis in recent years on the climatic effects of/controls on mesoscale processes, the socioeconomic impact of such phenomena, and climate change monitoring and detection. Outreach activities are also performed in a number of ways described later in this report.

CIMMS promotes cooperation and collaboration on problems of mutual interest among OU research scientists and students and the NOAA Office of Oceanic and Atmospheric Research (OAR) National Severe Storms Laboratory (NSSL), National Weather Service (NWS) Radar Operations Center (ROC) for the WSR-88D (NEXRAD) Program, NWS NCEP (National Centers for Environmental Prediction) Storm Prediction Center (SPC), NWS Warning Decision Training Branch (WDTB), and a NWS Forecast Office, all located in Norman, Oklahoma. CIMMS also fosters collaboration with the NWS National Environmental Satellite, Data, and Information Service (NESDIS) National Climatic Data Center (NCDC) in Asheville, NC, and with the NWS Southern Region Headquarters (SRH) in Fort Worth, TX.

CIMMS research contributes to the NOAA mission through improvement of the observation, analysis, understanding, and prediction of weather elements and systems and climate anomalies ranging in size from cloud nuclei to multi-state areas. Advances in observational and analytical techniques lead to improved understanding of the evolution and structure of these phenomena. Understanding provides the foundation for more accurate prediction of hazardous weather and anomalous regional climate. Better prediction contributes to improved social and economic welfare. Because small-, meso-, and regional-scale phenomena are also important causes and manifestations of climate, CIMMS research is contributing to improved understanding of the global climate system and regional climate variability and change. CIMMS promotes research collaboration between scientists at OU and NOAA by providing a center where government and academic scientists may work together to learn about and apply their knowledge of mesoscale weather and regional-scale climate processes.

CIMMS is part of the National Weather Center, a unique confederation of federal, state, and OU organizations that work together in partnership to improve understanding of the Earth's atmosphere. Recognized for its collective expertise in severe weather, many of the research and development activities of the Center have served society by improving weather observing and forecasting, and thus have contributed to reductions in loss of life and property. Many entities of the National Weather Center played a key role in the decade-long, $2 billion dollar modernization and restructuring of the National

Weather Service. National Weather Center organizations employ nearly 650 men and women and provide more than $45 million annually to the Oklahoma economy.

In addition to CIMMS, National Weather Center organizations include:

- NOAA OAR National Severe Storms Laboratory
- NOAA NWS Warning Decision Training Branch
- NOAA NWS NCEP Storm Prediction Center
- NOAA NWS Radar Operations Center
- NOAA NWS Weather Forecast Office - Norman, OK
- Oklahoma Climatological Survey
- OU College of Geosciences
- OU School of Meteorology
- OU Department of Geography
- OU Center for Analysis and Prediction of Storms
- OU Center for Spatial Analysis
- OU Environmental Verification and Analysis Center
- OU International Center for Natural Hazards and Disaster Research
- OU Sasaki Applied Meteorology Research Institute
- OU Supercomputing Center for Education and Research

This report describes the research progress made by CIMMS scientists at OU and those assigned to our collaborating NOAA units during OU fiscal year 2004 (1 July 2003 through 30 June 2004), and as such represents the third of five annual reports to be written for the present cooperative agreement (NA17RJ1227). CIMMS concentrates its research efforts and resources on the following principal themes: (1) basic convective and mesoscale research, (2) forecast improvements, (3) climatic effects of/controls on mesoscale processes, (4) socioeconomic impacts of mesoscale weather systems and regional-scale climate variations, (5) Doppler weather radar research and development, and (6) climate change monitoring and detection. Activities in Public Affairs and Outreach are also presented, along with information on publications written, awards received, and employee and funding statistics.

Executive Summary of Important Research Activities and Results during FY2004

Basic Convective and Mesoscale Research

The primary goals of this original CIMMS thematic area are to understand cloud and mesoscale dynamics, microphysics and the precipitation process and their relationships to large and small scale forcing, and to develop procedures for assimilation of meteorological data into simulation and prediction models of these processes. The work done here represents a fundamental building block for eventual applied techniques.

During the past year, research was conducted to:

- Test an ensemble Kalman filter as a method for retrieving the wind, thermodynamic, and microphysical fields in convective storms from radar observations
- Use idealized one and two dimensional models to explain reflectivity structures observed in tornadoes and quantify the difference between air motion and radar-scatterer motion
- Within the research phase of the field program TELEX, test and revise hypotheses concerning the interrelationships among the wind field, microphysical characteristics, electrical structure, and lightning of isolated severe storms and of large storm systems, to eventually improve thunderstorm forecasts and warnings
- Gain insight into electrification and microphysical processes and lightning behavior of thunderstorms

- Develop an improved understanding about cold fronts by studying the structure, evolution, and dynamics of prefrontal wind shifts and troughs; such prefrontal wind shifts/troughs can lead to potential aviation hazards and/or convective initiation
- Develop an understanding of the propagation mechanisms of mesoscale convective systems in numerical weather prediction models that use parameterized convection and investigate whether this mechanism can be used to predict the evolution of such systems more accurately.
- Within the research phase of the field program IHOP, determine conditions for initiation of convective storms, cumulus formation, or suppression of moist convection, and test the hypothesis that moist air rising in mesoscale boundary layer updrafts must achieve its LCL (LFC) prior to leaving the updraft to form cumuli (storms); corollary work sought to determine conditions for initiating new convection along the cold pool boundary to maintain mesoscale convective systems and bow-echoes
- Improve our fundamental understanding of the environments and mechanisms responsible for the development and maintenance of widespread severe convective windstorms, known as derechos, by identifying common large-scale environments associated with the development of derecho-producing convective systems using statistical clustering of a large number of events, and producing a set of horizontally homogeneous cloud-model simulations to determine the mechanisms that help support the longevity of these systems
- Examine observational data and explore the effects of hailstreaks on boundary layer evolution
- Assess the importance of horizontal radiative transfer on the evolution of radiatively-forced planetary boundary layer clouds
- Develop a parameterization of cloud variability for use in climate and numerical weather prediction models
- Increase understanding of the feedbacks between cloud microphysical, radiative and dynamical processes, and develop cloud and radiation parameterizations for use in numerical weather prediction models
- Continue theoretical studies on nearly symmetric and nearly baroclinic instabilities in the presence of diffusivity and examine their energetic aspects, and study nonlinear oscillations of baroclinic waves caused by mesoscale frontal processes and related vertical motions
- Advance knowledge and skill in storm-scale data assimilation, and develop state-of-the-art technologies and software for real-time applications of remotely sensed high-resolution measurements, especially those from Doppler radars, to improve numerical nowcasts and forecasts of severe storms and hazard weather conditions
- Advance knowledge and skill in surface and soil data assimilation, and develop state-of-art techniques for applications of ARM Program and Oklahoma Mesonet surface and soil data.
- Determine how environmental factors, notably the forcing that initiates deep convection and the environmental wind and thermodynamic profiles, control the time-dependent behavior of deep convective storms; also, collect and categorize past synoptic scale tornado outbreak events and estimate supercell storm motion using hodographs.
- Identify the dynamical mechanisms of vertical vortex formation in the convective boundary layer and assess the role of these vertical vortices on boundary layer processes
- Analyze Martian dust devil characteristics as determined by Mars Orbiter Camera (MOC) images and make comparisons with terrestrial dust devils, gaining insight into dust devil formation and maintenance dynamics, and their role in boundary layer processes, by comparison of their characteristics in two different atmospheres
- Examine the formation of vertical vortices within idealized ellipsoidal convective elements in quiescent ambient flows, and explore the effects of ambient winds, stratification, multiple convective elements, and other variables on the formation of these vortices
- Explore the consistency of certain microphysical parameterizations with the physical processes they are designed to represent
- Investigate the dynamics and microphysics of cirrus outflow anvils, isolate the conditions under which mammatus clouds form and are detectable, and make case studies of mammatus events and null events to help assess the role of dynamical and microphysical processes in mammatus cloud formation

Forecast Improvements

The primary goal of this original thematic area is to accelerate the transfer of research knowledge and skills between the academic and NOAA operational mesoscale meteorological communities to both improve the design and utilization of mesoscale weather observing systems and improve mesoscale weather prediction and warning.

During the past year, research was conducted to:

- Investigate warning decision making issues with NWS forecasters to evoke a better understanding of the warning decision making process and transfer that knowledge to warning decision makers to improve performance
- Develop applications to improve forecaster knowledge of warning-related issues and improve our understanding of warning-related issues
- Develop simulation capabilities to enhance warning decision making research and training
- Develop GIS basin datasets with hydrologic connectivity attributes for use in the Flash Flood Monitoring and Prediction System in AWIPS, and provide technical support and assistance to NWS Forecast Offices for their FFMP basin dataset customization efforts
- Develop, test, and evaluate polarimetric radar outputs for operational meteorology and test and evaluate prototype radar applications at NWS Forecast Office in Norman
- With WDSS-Integrated Information, improve the accuracy and timeliness of severe weather warning applications for the NWS and other users by integrating multiple-radar and multiple-sensor data
- Design and execute an annual collaborative SPC/NSSL spring program that allows forecasters to evaluate new tools or concepts that emanate from the research community, while immersing research scientists in the challenges, needs, and constraints of the operational forecasting environment
- Increase forecaster awareness and understanding of the WRF model by systematically evaluating model utility as an operational tool for forecasting severe convective weather and providing feedback to WRF developers based on model evaluation at the SPC
- Develop new and unique forecast verification strategies, and maintain and continue to build a database of forecasts and observations for ongoing verification studies
- Improve forecasts of temperature, dewpoint temperature, and winds over the New England region using a multimodel short-range ensemble forecasting system in comparison to present operational guidance provided by Model Output Statistics (MOS), and evaluate the value of multimodel ensembles for short-range forecasting
- Investigate the intraseasonal variability of diurnal storm development over Arizona and the importance of synoptic-scale forcing during the North American Monsoon
- Refine and further develop the Kain-Fritsch convective parameterization and to consult with worldwide users of the scheme
- Determine how changes in land use in the U.S. Southern Great Plains can influence a forecast from a mesoscale numerical model
- Determine if gradient information derived from scalar observations can be used to improve the analysis of the scalar itself
- Develop a mobile wireless network for communicating real-time mesoscale weather observations in mobile field experiments, a technology that could potentially assist short-range severe weather forecasting and other applications requiring wireless mobile digital communications at high bandwidth
- Facilitate CIMMS and NSSL scientists in developing multiple-sensor severe weather and flash flood applications for NWS operational systems, and set up an AWIPS Development Environment at CIMMS/NSSL in order to eventually establish several multi-sensor severe weather testbeds at select NWS forecast offices nationwide
- Provide research support to the operational forecasting activities at the SPC to improve forecasts of mesoscale hazardous weather

- Study system response and extraction times associated with different display and extraction methodologies using the Internet
- Formulate improvements in how regional models represent cloud-aerosol interactions; characterize cloud processing of aerosol in COAMPS using the CIMMS bulk drizzle scheme
- Develop a prototype visually-accurate weather data rendering system, using the latest computer graphics technology
- Develop a tool to help forecast the evolution of warm season mesoscale convective systems that affect the central and eastern United States during late morning, and gain a better understanding of the environmental factors that influence the evolution of these systems
- Develop a quality controlled data set of meteorological and hydrologic observations from Oklahoma Mesonet to obtain new insights of land-atmosphere interactions from diagnostic studies using such data; identify the parameterizations in the NOAH LSM that are sensitive to land surface conditions and use Mesonet data to modify, improve, and test the parameterizations to produce reduced model variability
- Identify radar echo structures common to the onset of heat burst activity in the Great Plains
- Develop the radar data assimilation components for the WRF 3DVAR system; develop a 4DVAR based soil temperature and moisture retrieval system for use in mesoscale models and improve land surface models; contribute to the development and testing of WRF model system.

Climatic Effects of/Controls on Mesoscale Processes

The primary goal of this thematic area is to extend and apply the understanding of mesoscale processes to the problem of climate maintenance and change. This theme also includes investigation of the influence of the large-scale climatic environment on the mesoscale systems that produce growing season rainfall in regions such as central North America and Sub-Saharan Africa.

During the past year, research was conducted to:

- Investigate land-atmosphere interactions on different time-scales over the agriculturally important U.S. Midwest using moisture budget analysis, an original recycling technique, crop yields, and soil moisture and solar radiation data
- Study the spatial and temporal variability of cyclones over the North Atlantic basin
- Examine and understand the intraseasonal variations of rainfall patterns over Sahelian countries within the framework of the dominant influence of the Intertropical Front and the deep convergence zone

Socioeconomic Impacts of Mesoscale Weather Systems and Regional Scale Climate Variations

The primary goal of this thematic area is to estimate the socioeconomic impacts and values of mesoscale weather systems and regional-scale climate variations in central and eastern North America and across the world, to facilitate the mitigation (enhancement) of the adverse (beneficial) impacts. A continuing component of this work makes extensive use of climate scenarios and economic models, and is performed in collaboration with agricultural economists and social scientists. It is also complemented by a research thrust that is addressing a spectrum of weather- and climate-related disaster issues.

During the past year, research was conducted to:

- Develop monthly and seasonal residential natural gas consumption indices east of the Rocky Mountains
- Study the economic impacts of tornadoes and hurricanes, focusing specifically on the benefits of tornado shelters, the safety benefits with respect to tornadoes of Doppler radar, and the possible causes of increased societal vulnerability to hurricanes

- Understand the physical and dynamical processes responsible for creating an intraseasonal cool anomaly over the U.S. Southern Great Plains during summer 2002, and to identify predictable characteristics of the anomaly to help improve forecasts of similar reoccurrences at lead times exceeding 10 days, thereby helping to mitigate social and economic losses
- Examine rainfall variability and its effects on crops, societies, and economies of Mali, Burkina Faso, and Côte d'Ivoire

Doppler Weather Radar Research and Development

The primary goal of this thematic area is to accelerate the transfer of knowledge between the meteorological and engineering communities (in academia, and government and private laboratories) to improve the design, usability, and supportability of the NEXRAD WSR-88D Doppler weather radar. Continual enhancements are needed to the system for improving the quality, format, accuracy, resolution, and update rate of the base data, and to keep pace with evolving hardware and software technologies. This work introduces, examines, and analyzes present and future technologies, including phased-array technology, with the goal of meeting the unfulfilled radar needs. This theme also includes a fertile research area for development and improvement of radar algorithms used for forecasting and warning.

During the past year, research was conducted to:

- Continue efforts leading to improved estimation of precipitation using QPESUMS for flash flood monitoring and prediction, watershed management, inputs to hydrologic models and near storm-scale models, and for verification of high-resolution numerical weather forecasts
- Provide a seamless three-dimensional radar reflectivity mosaic (NMQ) for the conterminous U.S. that has high spatial resolution and rapid update cycle for severe weather applications and for mesoscale numerical weather model data assimilation
- Provide accurate conterminous U.S. precipitation estimates over a high-resolution grid with a rapid update cycle for flash floods and flood warnings, and for water resource management
- Develop better WSR-88D applications and algorithms and transfer the technology to the ROC for NEXRAD Tri-Agency use
- Create a platform-independent tool (VCPExplorer) for visualizing radar propagation path with respect to the terrain surrounding the radar, provide additional enhancements for forecaster training (such as display of non-standard beam propagation using point soundings), and display radar algorithm output dependent on range from radar and volume coverage pattern (VCP)
- Complete JPOLE data analyses and produce reports to demonstrate the utility of a polarimetric WSR-88D (KOUN) and support a decision briefing to the NEXRAD Program Management Committee (NPMC) on upgrading the national network of WSR-88D radars to include polarimetric capabilities
- Create new algorithms that exploit the expanded capabilities of dual-polarization radar, and develop techniques to provide improved data quality for the prototype polarimetric KOUN WSR-88D radar
- Mitigate range and velocity ambiguities in WSR-88D data
- Improve Doppler spectral moment and polarimetric variable estimates through use of a pseudowhitening transformation on oversampled range data
- With the Shared Mobile Atmospheric Research and Teaching Radar (SMART-R), study convective and mesoscale atmospheric processes to help improve forecasts of significant weather events such as flash floods, hurricanes, and tornadoes
- For the KOUN radar, provide visual feedback of time series spectra at selected gates to traditional moment displays (i.e., PPI views), and link the time series data and moment data together to improve identification of meteorological and non-meteorological targets
- Assess the operational benefit as well as the engineering/performance impact of implementing "super resolution" (0.5 degree azimuthal resolution and 0.25 km reflectivity range resolution) base data on the WSR-88D network
- Evaluate radar data quality issues of Korean Meteorological Administration (KMA) radars and identify solutions to improve their radar data quality

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- Prepare the National Weather Radar Testbed (NWRT) Phased Array Radar (PAR) for scientific and engineering evaluation
- Perform engineering analyses of PAR data to identify and assess data quality issues associated with the new system, and use these analyses to prioritize and resolve identified issues
- Begin meteorological analyses of PAR data to evaluate the utility of using PAR technology for meteorological purposes
- Develop and install material and software to allow for continuous rotation of the PAR antenna
- Improve the Radar Scheduler component of the PAR, which is the primary interface between the user and the radar
- Evaluate and improve WSR-88D algorithms such as MPDA and SAA, and perform data quality assessments
- Analyze data from the prototype ORDA and dual polarization radar systems to better understand how the data can best be used by forecasters, and transfer the new understanding to operational forecasters before the installation of the new systems
- Perform a dual-Doppler radar intercept and analysis of a tornado-producing supercell
- Improve tornado detection by identifying vortex signatures in the Doppler spectrum obtained from WSR-88D data
- Provide radar data transmission to the government and private sector
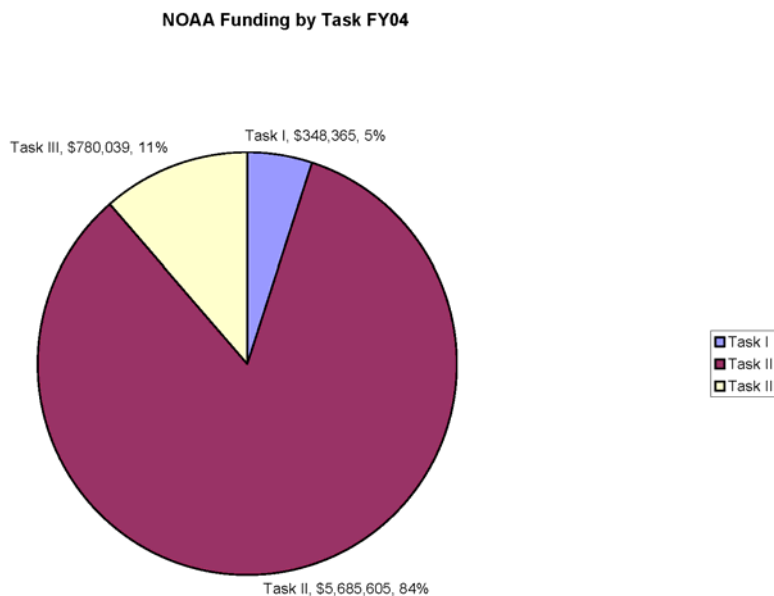
Climate Change Monitoring and Detection

The goal of this research theme is to study climate change monitoring and detection in general, and specifically the homogeneity or lack thereof of the historical station records in the U.S. and to use this information to help address the climate change questions.
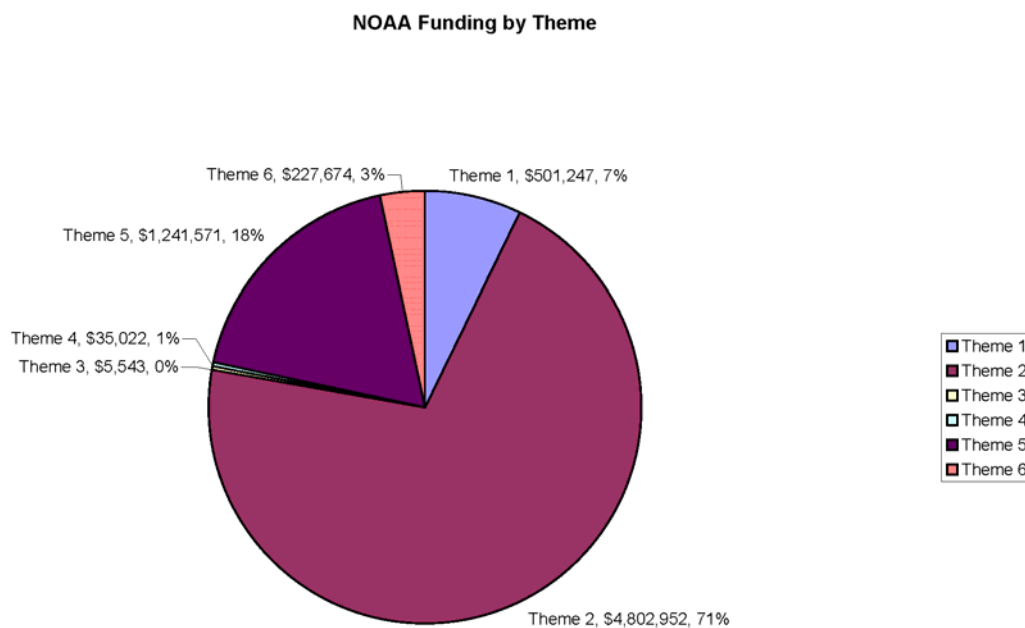
During the past year, research was conducted to:

- Evaluate U.S. climate indices from observational and model data, document the quantitative character of observed climate changes in the U.S. over the last century, and attribute the observed changes to specific climate forcings, where possible
- Determine summertime temperature extremes in North America east of the Rocky Mountains
- Investigate the time series behavior of the seasonal signal of the North Atlantic
- Investigate the low frequency variability of sub-Saharan precipitation
- Analyze rainfall trends in the Sahel to diagnose drought conditions
- Inspect and assess U.S. DOE ARM Program data from the Southern Great Plains, Tropical Western Pacific, and North Slope of Alaska sites on a near real-time basis, and provide support to ARM Program site operators, site scientists, and instrument mentors to solve instrument measurement problems
- Provide scientific support for U.S. DOE ARM Program Southern Great Plains site operations, conduct a site-relevant research program, and conduct educational outreach activities
- Enhance the quality and quantity of Pacific rainfall data and help build capacity for the Pacific National Meteorological Services
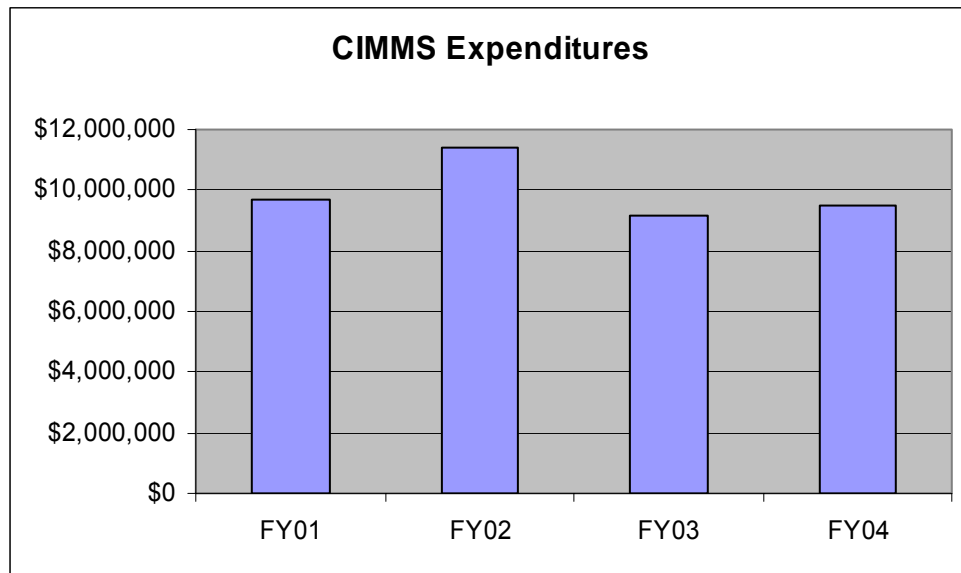
# Distribution of NOAA Funding by CIMMS Task and Theme

NOAA Funding by Task FY04

Task III, $780,039, 11%
Task I, $348,365, 5%

Task II, $5,685,605, 84%

Legend:
- Task I
- Task II
- Task III

NOAA funding to CIMMS by Task during FY04.

NOAA Funding by Theme

Theme 6, $227,674, 3%
Theme 1, $501,247, 7%
Theme 5, $1,241,571, 18%
Theme 4, $35,022, 1%
Theme 3, $5,543, 0%

Theme 2, $4,802,952, 71%

Legend:
- Theme 1
- Theme 2
- Theme 3
- Theme 4
- Theme 5
- Theme 6

NOAA funding to CIMMS by Research Theme during FY04.

CIMMS Expenditures

Overall research expenditures at CIMMS during the past four fiscal years.

CIMMS Expenditures 2003-2004
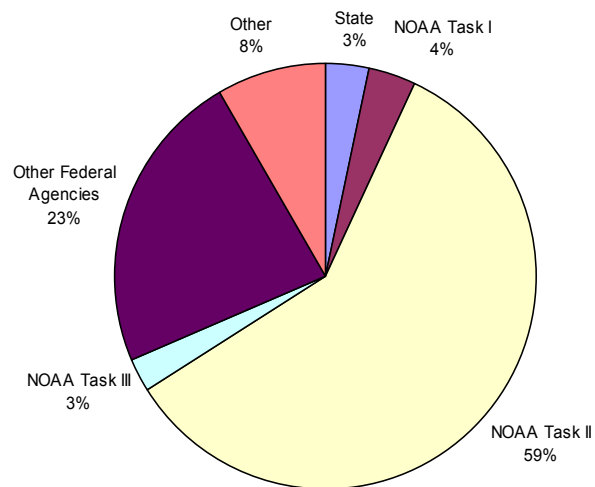
Breakdown of overall CIMMS research expenditures by general funding source during FY04.

RESEARCH PERFORMANCE

Basic Convective and Mesoscale Research

NSSL1: Convective Weather Research – *Ensemble Kalman Filter Assimilation of Multisensor Observations from Convection for Storm-Scale Analysis*
Dowell, **Wicker**, **Shapiro**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop techniques for assimilation of Doppler radar observations into cloud-scale models for analysis and forecasts using an Ensemble Kalman Filter approach; understand the issue of model error as it relates to microphysical parameterization error, and how it impacts the data assimilation and how it might be mitigated by other *in situ* data.

Accomplishments
The ensemble Kalman filter (EnKF; Evensen 1994; Houtekamer and Mitchell 1998) is currently being tested as a method for retrieving the wind, thermodynamic, and microphysical fields in convective storms from radar observations (Snyder and Zhang 2003; Zhang et al. 2004; Dowell et al. 2004; Tong and Xue 2004). Applications for such retrievals include diagnosing storm processes and initializing numerical storm-scale forecast models. The EnKF technique for storm-scale retrieval is being refined according to the results of both Observing System Simulation Experiments (OSSEs) and real-data experiments.

We are currently applying the EnKF method to a real-data case the 8 May 2003 supercell thunderstorm that produced an F4 tornado in Oklahoma City, Oklahoma. During the afternoon of 8 May 2003, several convective cells formed along a dryline in west-central Oklahoma (see figure below). Of these cells, only one evolved into a tornadic supercell. The life cycle of the Oklahoma City storm was documented by the KOUN radar, a 10-cm dual-polarization research Doppler radar in Norman, Oklahoma. By assimilating Doppler velocity and reflectivity observations from the KOUN radar into a numerical cloud model during the storm's development stage and then producing 40-min forecasts, we aim to (1) understand the storm evolution during the development state, and (2) determine how well the later storm during the tornadogenesis stage can be predicted.

Publications
Dowell, D. C., F. Zhang, L. J. Wicker, C. Snyder, and N. A. Crook, 2004: Wind and temperature retrievals in the 17 May 1981 Arcadia, Oklahoma, supercell: Ensemble Kalman filter experiments. *Mon. Wea. Rev.*, **132**, 1982-2005.
Dowell, D. C. and L. J. Wicker, 2004: High resolution analyses of the 8 May 2003 Oklahoma City Storm. Part II: EnKF assimilation experiments and forecasts. *Preprints, 22nd Conf. of Severe Local Storms*, Hyannis, MA. Paper 12.5
Wicker, L. J. and D. C. Dowell, 2004: High resolution analyses of the 8 May 2003 Oklahoma City Storm. Part II: A ultra-high resolution forecast experiment. *Preprints, 22nd Conf. of Severe Local Storms*, Hyannis, MA. Paper 12.6
Dowell, D. C., C. R. Alexander, J. M. Wurman, and L. J. Wicker, 2004: Reflectivity Patterns and wind-measurement errors in high-resolution radar observations of tornadoes. *Mon. Wea. Rev.*, submitted.
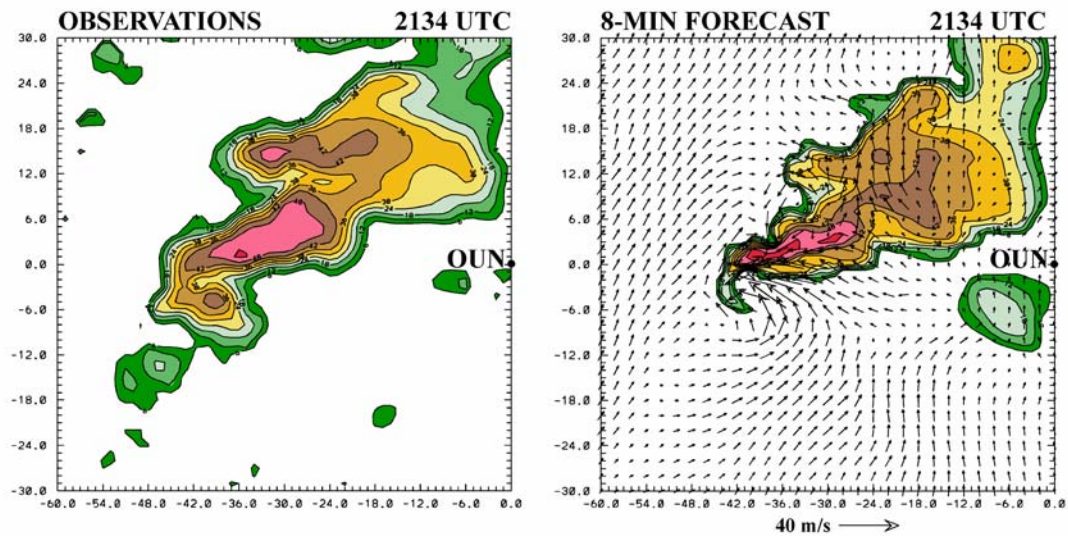
Figure 1. Observed (left) and model-forecast (right) reflectivity (contours and shading at intervals of 6 dBZ$_e$) at 2134 UTC at 2.0 km AGL in a 60 km × 60 km portion of the 150 km × 150 km domain. Horizontal storm-relative winds in the model are also shown.
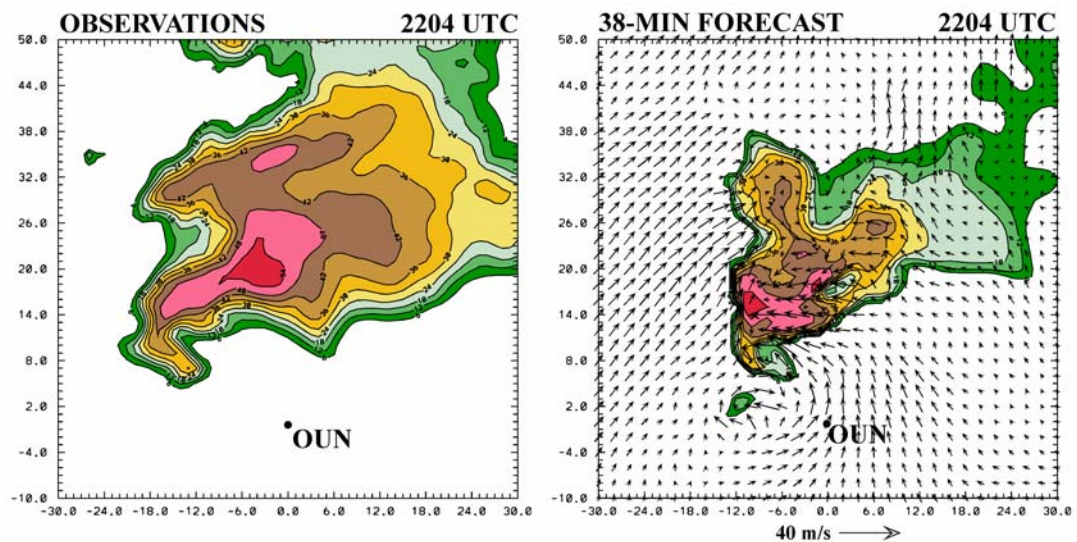

Figure 2. As in Fig. 7, except at 2204 UTC.

Results from our real data assimilation analysis and forecast experiment for the 8 May 2003 OKC tornadic storm. On the left is the observed radar reflectivity from the KOUN radar. On the right is the model forecast at T=8 minutes and 38 minutes. The 38 minute forecast corresponds to the time of tornado touchdown in southwest Oklahoma City and the forecast shows maximum rotation near the ground at this time.

NSSL1: Convective Weather Research – *Reflectivity Structures in Tornadoes*
Dowell, **Wicker**, Alexander, Wurman

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Use idealized 1D and 2D models to explain reflectivity structures observed in tornadoes; quantify the difference between air motion and radar-scatterer motion, a source of "measurement error".
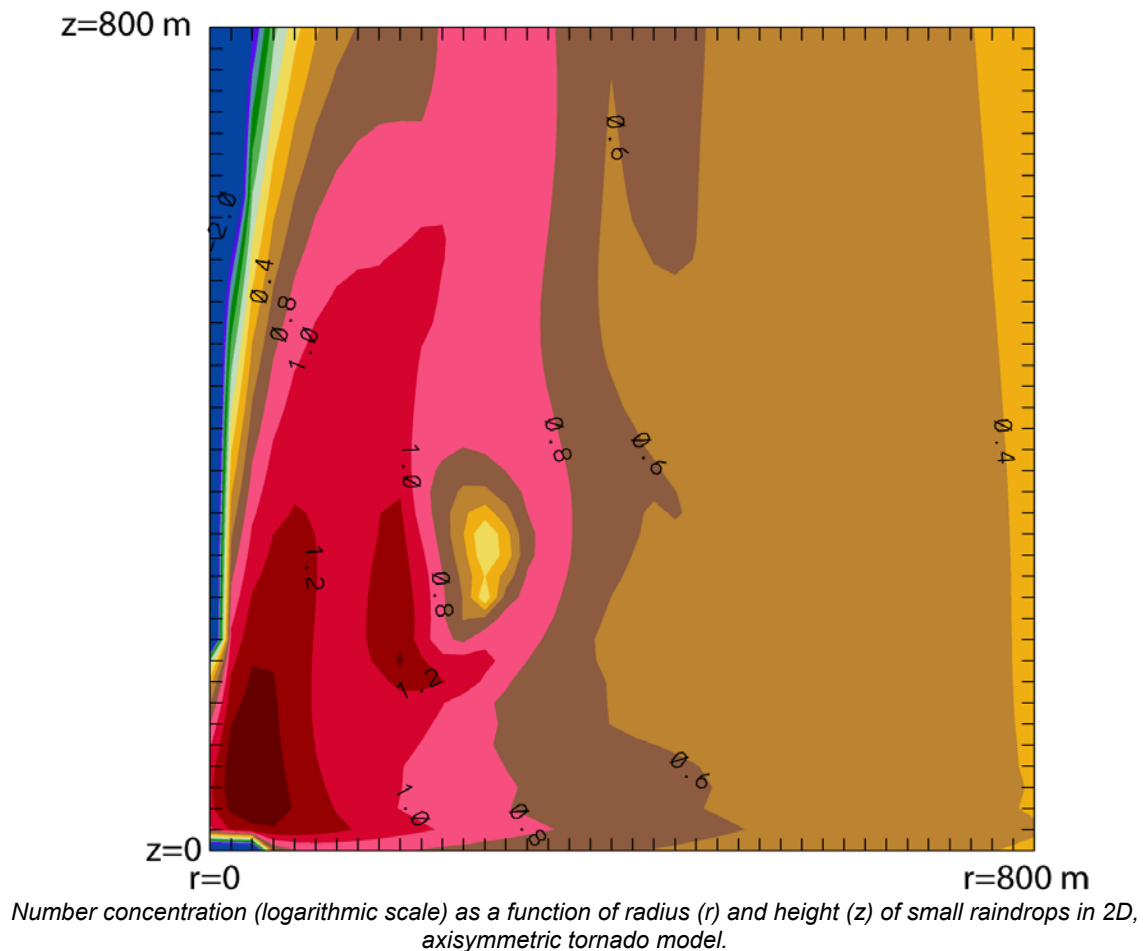
Accomplishments
High-resolution radar observations of tornadoes indicate that tornadoes are associated with a high-reflectivity tube that surrounds a low-reflectivity core. The results of simple 1D and 2D models demonstrate how these characteristics develop. The near-surface inflow and updraft concentrate scatterers (hydrometeors and/or debris) at low levels and carry them upward. Aloft, the rotating flow centrifuges the hydrometeors/debris and produces a minimum in number concentration in the core.

When analyzing Doppler observations, one typically assumes that the Doppler measurements represent the air flow. This assumption is a source of "measurement error" in tornado observations because scatterers can move at velocities that are significantly different than those of the air. The 1D and 2D models can be used to quantify this measurement error for various scatterer types.

Publications
Dowell, D. C., C. R. Alexander, J. M. Wurman, and L. J. Wicker, 2004: Centrifuging of hydrometeors and debris in tornadoes: Radar-reflectivity patterns and wind-measurement errors. *Mon. Wea. Rev.*, accepted.

Number concentration (logarithmic scale) as a function of radius (r) and height (z) of small raindrops in 2D, axisymmetric tornado model.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Thunderstorm Electrification and Lightning Experiment (TELEX)*
MacGorman, **Rust**, **Schuur**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
The scientific purpose of TELEX is to test and revise hypotheses concerning the interrelationships among the wind field, microphysical characteristics, electrical structure, and lightning of isolated severe storms and of large storm systems, with long term objectives to improve thunderstorm forecasts and warnings.

Accomplishments
Year two (of two) of the field program for TELEX was conducted in central Oklahoma during 9 May-28 June 2004. Several upgraded observing systems operated in central Oklahoma: the polarimetric KOUN 10-cm wavelength Doppler radar, the Oklahoma three-dimensional lightning mapping array (OK-LMA), the two SMART Radars, mobile environmental soundings, and a mobile laboratory for storm intercept and mobile ballooning with up to four balloon soundings being made simultaneously. Also, the balloon-borne electric field meters were substantially upgraded to make them more able to survive high-wind launches and to provide higher resolution three-dimensional electric field vectors in context of the three-dimensional structures of storm parameters and lightning. Two adjunct experiments also participated in TELEX: a lightning x-ray detector and an electric field change detector from New Mexico Institute of Mining and Technology, and an electric field detector for above storm measurements from the University of Washington.

Thirty-six flights, each with a GPS radiosonde and an electric field meter, were made into storms during thirteen ballooning missions. The flights were into a variety of storm types, including multicellular storms, supercells, and mesoscale convective systems (MCS). Electric fields ranging to about 150,000 Vm^{-1} were measured. The field program was very successful, and analyses of data have begun. The primary near-term emphasis is on the three-dimensional polarimetric radar, lightning mapping, dual-Doppler, and electric field.

Publications
Rust, D., D. MacGorman, T. Schuur, J. Straka, B. Rison, T. Hamlin, P. Krehbiel, and E. Bruning, 2003: Overview of the Year-One Field Program Phase of the Thunderstorm Electrification and Lightning Experiment (TELEX) 2003. *Eos Trans. AGU*, **84(46)**, Fall Meet. Suppl., Abstract AE32A-0165.
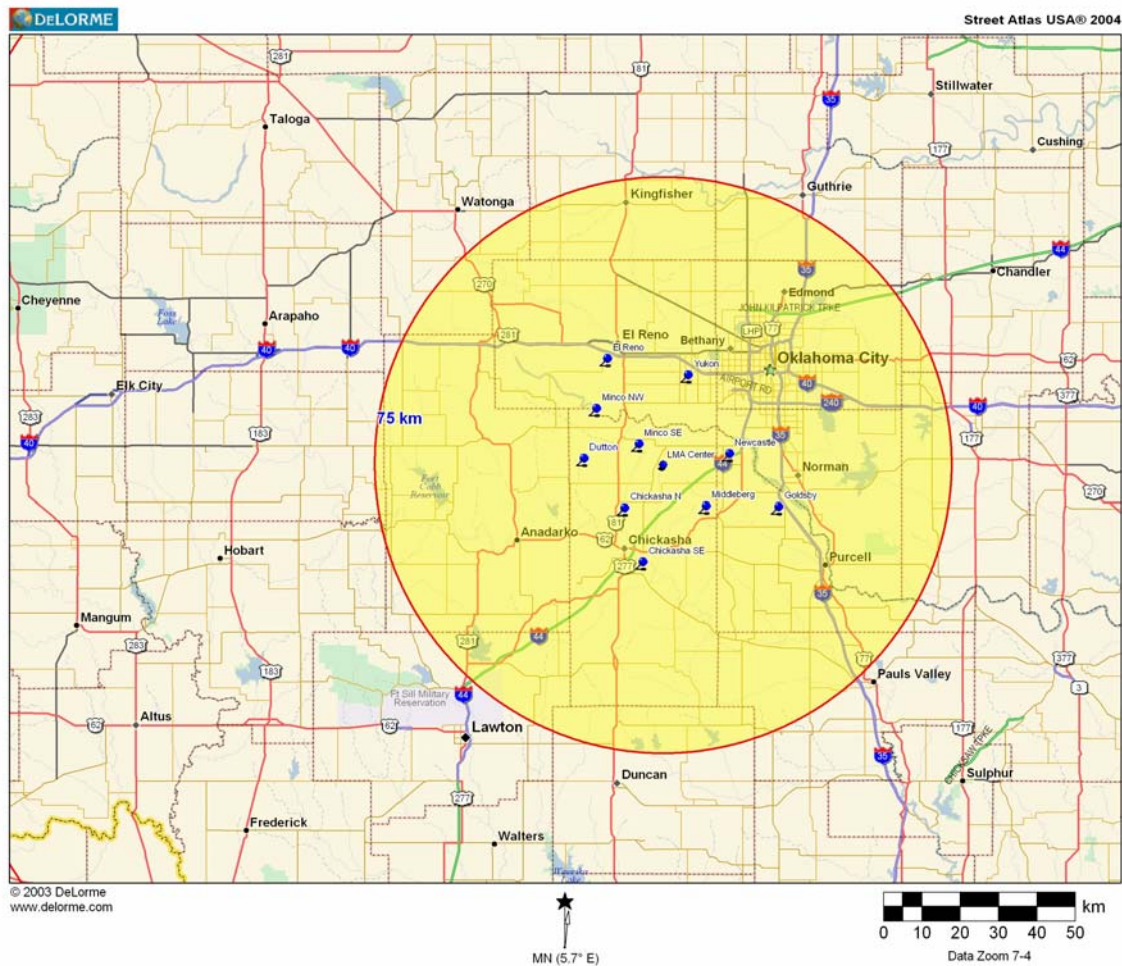
TELEX 2003-2004 data collection area. The yellow circle indicates the coverage region of the three-dimensional mapping by the Oklahoma Lightning Mapping Array (OK-LMA), which is also the primary region of TELEX field operations in 2003 and 2004. Blue pins mark the locations of the OK-LMA receiving sites. For 2004, a site at Will Rogers Airport site was decommissioned, and a new one was added at Dutton. The coverage was about the same in both years.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Thunderstorm Electrification Modeling*
Mansell, Straka, Ziegler, MacGorman, Kuhlman

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Gain insight into electrification and microphysical processes and lightning behavior of thunderstorms.

Accomplishments
Our modeling studies of thunderstorm electrification and lightning have advanced on a number of fronts. Ice crystal concentrations at temperatures of 0° to -15°C have been found to be an important factor in the effectiveness of noninductive charge separation in the development of lower positive charge regions. Previous modeling results have also identified inductive charge separation between graupel and cloud droplets as a possible primary mechanism for lower positive charge. "Lightning holes" that have been observed in lightning mapping data from supercell storms have been reproduced in a model simulation. The conditions for the simulated holes concur with the hypothesis that they arise with updraft

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intensification and the development of a bounded weak-echo region. Another new result for the 29 June 2000 supercell found good correlations between lightning flash rate and graupel volume, updraft volume (> 10 ms^{-1}), with linear correlation coefficients of 0.75 and 0.65, respectively, on average. Peak updraft speed was found to be a poor predictor of flash rate, with a correlation of only 0.1. Preliminary work on a study of MCS electrification also was completed with a nonelectrical simulation of an asymmetric MCS that included Coriolis effects and showed development of an MCV (mesoscale convective vortex) and stratiform precipitation.

Environmental soundings were collected during the TELEX 2004 campaign for a range of convective events for future model studies. Multiple soundings for two supercell storms documented the changing environment experienced by the storms. One of the storms (26 May 2004) dissipated within the coverage area of the OK-LMA (lightning mapping array). The storm exhibited interesting cloud-to-ground lightning behavior that will make for a challenging modeling study.

A study was completed showing the advantages of a bulk microphysics scheme with multiple ice precipitation categories (10-ICE) compared to a simpler scheme with only three ice species (3-ICE). The 10-ICE scheme exhibits a greater "dynamic range" of microphysical structure because mass can accumulate in a range of categories from low-density graupel to high-density large hail. An example simulation was the 9 August 1991 case of a small thunderstorm from the Convection and Precipitation Electrification (CaPE) field program (see figure).   The model captures the general features of rain and graupel formation that were observed in the storm that occurred in the vicinity of the atmospheric sounding used to initialize the model. Rain first forms by autoconversion and then freezes as it is lifted by the updraft. The model produces a slightly stronger storm with greater maximum reflectivity (65 dBZ) and updraft (25 ms^{-1}) than observed (55 dBZ and 20 m/s), but the maximum echo top heights are in good agreement with the observations. The electrification of this storm is also being investigated in an ongoing study. A preliminary result is that the modeled electrification and lightning best match the observations when the sign of charge transfer is a function of temperature and switches from positive to negative as the temperature goes below -10°C.

Publications

Kuhlman, K. M., 2004: Numerical Simulations of the 29 June 2000 STEPS Tornadic Supercell: Microphysics, Electrification, and Lightning, Masters Thesis, Univ. of Oklahoma, Norman, OK, 72 p.

Straka J. M. and E. R. Mansell, 2004: A bulk microphysics parameterization with multiple ice precipitation categories, *J. Appl. Met.,* conditionally accepted.

Mansell, E. R., D. R. MacGorman, C. L. Ziegler, and J. M. Straka, 2004: Charge structure and lightning sensitivity in a simulated multicell thunderstorm, *J. Geophys. Res.*, submitted.

Fierro, A. O., M. S. Gilmore, L. J. Wicker, E. R. Mansell, J. M. Straka, and E. N. Rasmussen, 2004: Electrification and lightning in an idealized boundary-crossing supercell simulation of 2 June 1995. *Mon. Wea. Rev.*, submitted.

Mansell, E. R., K. M. Kuhlman, C. L. Ziegler, J. M. Straka, and D. R. MacGorman, 2003: Model studies of lightning in thunderstorms. *EOS Trans. AGU*, **84(46)**, Fall Meet. Suppl., Abstract AE51B-01 (Invited).

Beasley, W. H., E. R. Mansell, R. Jabrezemski, B. Conway, M. Eilts, and L. G. Byerley, 2003: On the development of lightning hazard-warning decision-support criteria, *EOS Trans. AGU,* **84(46)**, Fall Meet. Suppl., Abstract AE22A-1107.
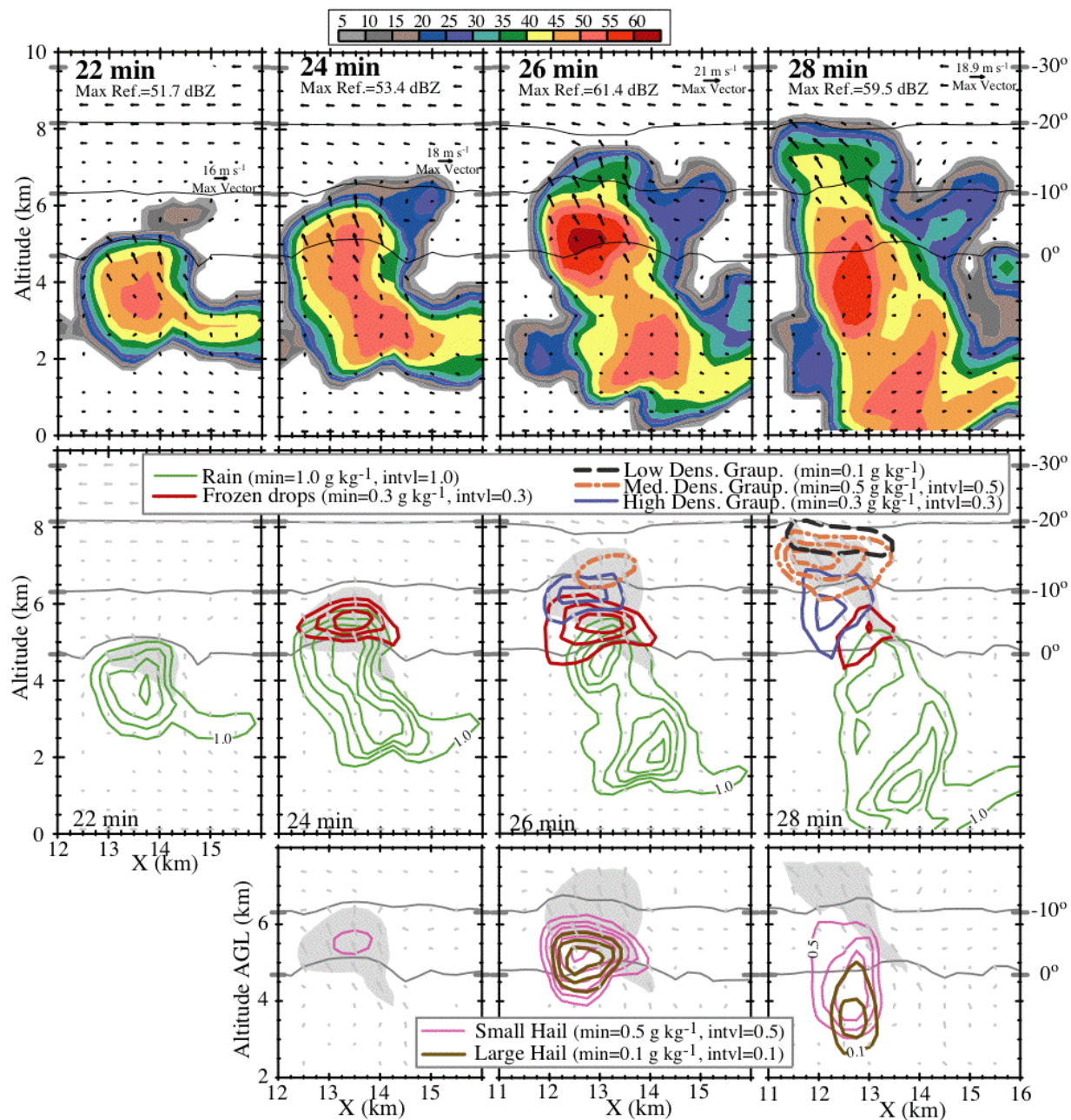
Maritime (Florida) cell development. The top row shows simulated reflectivity (5-dBZ increments). The middle row shows rain, frozen drops, and graupel mixing ratios. Small and large hail mixing ratios appear in the bottom row. All contours have constant intervals as indicated. The grayfill areas indicate updraft greater than 10 ms⁻¹, and wind vectors are storm-relative.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Cold Frontal Research*
Schultz, Trapp, Cohen, Roebber

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop an improved understanding about cold fronts. Specifically, an overarching theme of this research is the structure, evolution, and dynamics of prefrontal wind shifts and troughs. These prefrontal wind shifts/troughs can lead to potential aviation hazards and/or convective initiation.

Accomplishments
This research has numerous facets, as described in the papers listed below. There are idealized numerical models of cyclones and their attendant fronts (e.g., Cohen and Schultz 2004), a review article on prefrontal troughs/wind shifts (e.g., Schultz 2004b, c), and observations of prefrontal troughs/wind shifts (e.g., Schultz and Trapp 2003; Schultz 2004a). In addition, a mesoscale model simulation of the Sanders (1955) cold front is being analyzed by Schultz and Roebber. Sanders (1955) was the first, the simplest, and we would argue, still the best, quantitative study of the structure and dynamics of a cold front. Our goal is to reinvestigate the structure, evolution, and dynamics of that archetypal cold front from a modern perspective on the 50th anniversary of his work next year.

Other research that has been published or that has been submitted includes Schultz (2004a), which investigates the difference between cold fronts that possess prefrontal wind shifts/troughs in the central United States versus those that do not. This research shows that the timing and location of lee cyclogenesis relative to the cold front is fundamental in correctly forecasting the timing and strength of the cold front. Given that much effort has been put forth toward improving the forecasting of cold fronts through numerical modeling, this research shows that further improvements in modeling and observations are required to improve the timing and intensity of these cold fronts. This issue also is apparent with the mesoscale model simulation of the Sanders (1955) cold front, where obtaining a quality simulation of the cold front depends very intimately on forecasting correctly the lee cyclogenesis.

Publications
Cohen, R. A., and D. M. Schultz, 2004: Contraction rate and its relationship to frontogenesis, the Lyapunov exponent, fluid trapping, and airstream boundaries. *Mon. Wea. Rev.*, submitted.
Schultz, D. M., 2004a: Cold fronts with and without prefrontal wind shifts in the central United States. *Mon. Wea. Rev.*, **132**, 2040-2053.
Schultz, D. M., 2004b: A review of cold fronts with prefrontal troughs and wind shifts. *Mon. Wea. Rev.*, submitted.
Schultz, D. M., 2004c: Perspectives on Fred Sanders' cold-frontal research. The Fred Sanders Symposium Volume, *Meteor. Monogr.*, Amer. Meteor. Soc., submitted.
Schultz, D. M., and R. J. Trapp, 2003: Nonclassical cold-frontal structure caused by dry subcloud air in northern Utah during the Intermountain Precipitation Experiment (IPEX). *Mon. Wea. Rev.*, **131**, 2222-2246.
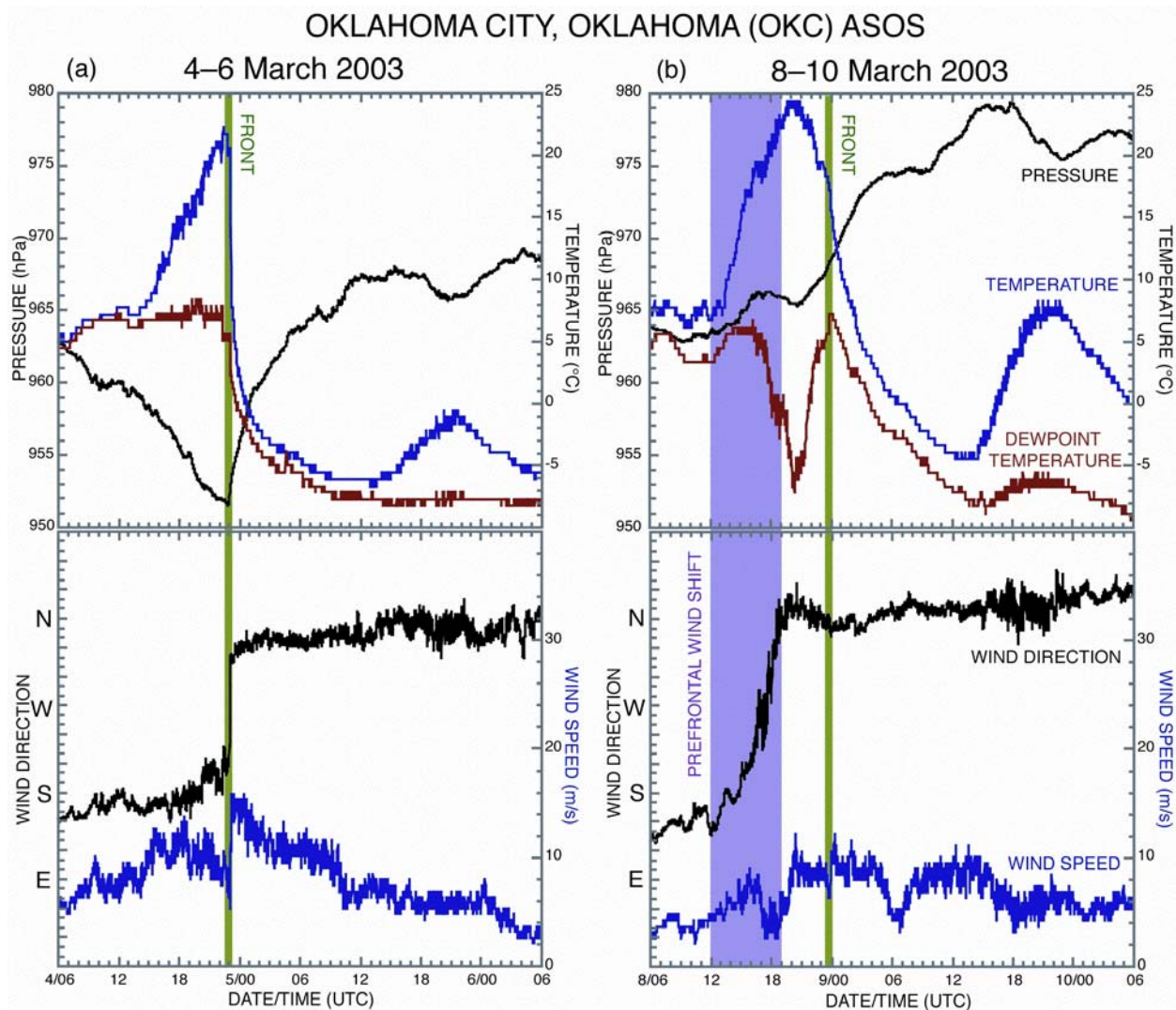
Frontal passages on 4--6 and 8--10 March 2003 from the one-minute data at the Automated Surface Observing System (ASOS) at Oklahoma City, OK (OKC). UTC=CST+6 h. This figure shows two frontal passages in OKC, just two days apart, yet showing very different structures. The cold front on 4 March was characterized by a coincident sharp wind shift, pressure trough, and a strong temperature decrease of 10°C in 2 minutes. On the other hand, the cold-frontal passage on 8 March was characterized by a prefrontal wind shift occurring over a 7-h period before the temperature decrease of 10°C in 2 hours.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Convective System Propagation in Models that Use Parameterized Convection*
Bukovsky, **Kain**, **Baldwin**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop an understanding of the propagation mechanisms of mesoscale convective systems in NWP models that use parameterized convection and investigate whether this mechanism can be used to predict the evolution of MCSs more accurately.

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Accomplishments

The convective parameterization used in the operational Eta model, the Betts-Miller-Janjic (BMJ) scheme, produces unique profiles of convective heating. In certain environments, these heating profiles can induce a distinct n=1 (full tropospheric) gravity-wave-like response in the model atmosphere. Lower tropospheric upward motion is one of the specific characteristics of this propagating response. Since this motion has a destabilizing effect on the atmosphere, it can trigger new convection along its path as it propagates away from its source. Under the right conditions, the new convection generates the same type of heating profile, reinforcing the gravity-wave-like response. When this force-response process occurs sequentially, the leading edge of parameterized convection propagates at about the phase speed of an n=1 gravity wave and the model effectively creates a propagating mesoscale convective system.

Identification and characterization of this process is important because numerical models must have skill in predicting propagation of MCSs if they are to simulate correctly the climatology of warm season rainfall over the U.S. Although current Eta model predictions of propagating systems often have significant directional error, the model seems to have skill in discriminating between those environments that will support strongly propagating convective systems and those that will not. Now that the mechanism of propagation is understood, additional refinements are likely to yield better overall prediction of propagating systems, numerical weather prediction, and rainfall climatology.

Publications

Bukovsky, M. S., 2004: Initiation and propagation of convection in forecast models using convective parameterizations. M. S. Thesis, University of Oklahoma

Bukovsky, M. S., and J. S. Kain, 2004: Predicting propagating convective systems using operational forecast models. *Preprints, 22nd Conference on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., CD-ROM, paper 17.7.
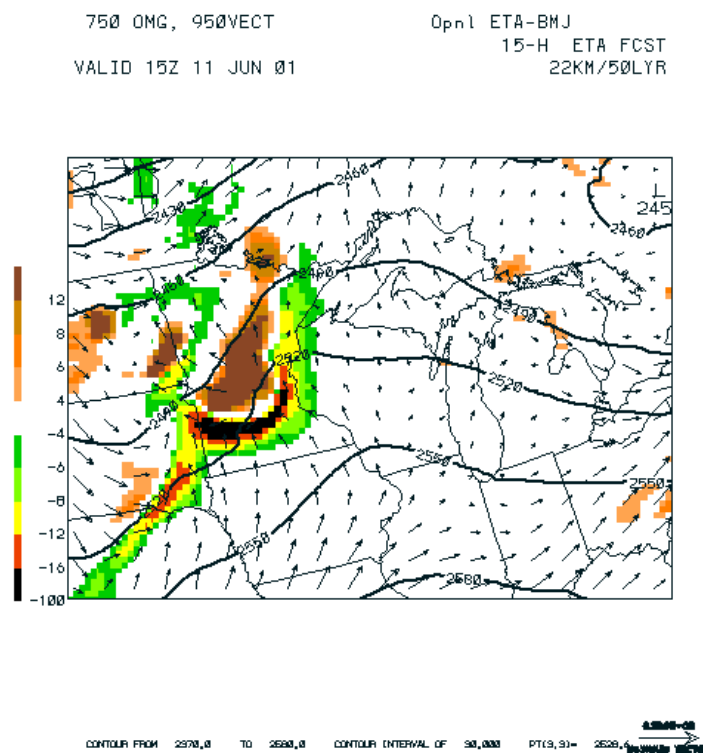
A 15-h forecast from the operational Eta model, valid 1500 UTC 11 June 2001, showing 750 hPa heights (contour interval = 30m), w (color fill in units of mb s^{-1}), and 950 hPa wind vectors. Pattern of w reveals a bow shaped "convective line", induced by parameterized convective heating, which was propagating strongly into lower tropospheric flow in the model. In reality, a strong bow echo formed in this environment, but it occurred later in the day and downstream from the predicted system.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Measurement and Analysis of the Preconvective Boundary Layer and Convection Initiation during IHOP*
Ziegler, **Rasmussen**, **Buban**, **Mansell**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Determine conditions for initiation of convective storms, cumulus formation, or suppression of moist convection; test the hypothesis that moist air rising in mesoscale boundary layer updrafts must achieve its LCL (LFC) prior to leaving the updraft to form cumuli (storms). A corollary objective is to determine conditions for initiating new convection along the cold pool boundary to maintain mesoscale convective systems and bow-echoes.

Accomplishments
Two-hour long series of three-minute interval multiple Doppler analyses from up to four mobile ground-based radars were prepared for the 22 May 2002 dryline and 24 May 2002 dryline/cold front triple point cases. Polarimetric and refractivity data from S-Pol radar were also analyzed in the 22 May case. Other data analyzed in both cases included: (1) in-situ measurements from nine mobile mesonets, two instrumented research aircraft, and mobile and fixed environmental soundings and dropsondes; (2) GOES visible satellite imagery; and (3) digital cloud field images from a ground-based camera. A new Lagrangian-based in-situ thermodynamic data analysis assimilates 4-D Doppler airflow and all available in-situ data to produce time-spaced, 3-D fields of potential temperature and water vapor mixing ratio, from which many useful derivative fields are obtained (e.g., parcel LCL height). The thermodynamic analysis is 3-D and is based on Lagrangians extended both upstream and downstream from in-situ observation locations within a chosen time window using the input 4-D radar analysis wind fields. Lagrangians are assigned observed values of the conservative variables at their initial points, followed by objective analysis to the radar analysis grid. With NOAA funding under this project line, Ziegler served as a chief scientist on the NOAA P-3 in the Bow-Echo and MCV Experiment (BAMEX-2003) and also obtained mobile environmental soundings of supercells and MCSs during the Thunderstorm Electrification and Lightning Experiment (TELEX-2004).

Our analyses resolve a cold front, drylines, horizontal convective rolls and open cellular convection, and mesoscale vortices in the boundary layer (BL). Airflow, reflectivity (Z), and differential reflectivity (Zdr) structures exhibit temporal continuity; some rolls, updraft cells, and mesovortices persist (with amplitude fluctuations) for up to about 45 minutes as they move with the boundary layer wind across the radar analysis domain. High Zdr sharply delineates internal convective BLs and upwells and recycles through the mesoscale updraft along the dryline, suggesting insect scatterers at 10 cm wavelength are active flow tracers. Lagrangian thermodynamic analyses reveal a sharply defined cold front, multiple drylines, and elevated residual layers overlying internal BLs. In the 24 May case, LCL height is within the radar analysis domain, and water saturation (cumuli) is achieved east of the dryline and along/behind the strong cold front. In the 22 May case, good agreement is obtained between Lagrangian and refractivity-based BL vapor mixing ratio, except in areas of apparent radar attenuation where the latter exhibits bias. Ziegler and Buban led preparation and presented preliminary analyses of the 24 May 2002 and 22 May 2002 IHOP cases (respectively) at the 31st Radar Meteorology conference, and formal manuscripts on these cases are in preparation for a special MWR issue on IHOP convection initiation studies. Buban has begun preparation of his M.S. thesis based on his 22 May dryline analyses.

Publications
Buban, M., C. Ziegler, and E. Rasmussen, 2003: The kinematic and thermodynamic effects of vortices within a dryline. *Preprints, 31st Radar Meteor. Conf.*, Amer. Meteor. Soc., Boston, 789-792.

Ziegler, C., E. Rasmussen, Y. Richardson, R. Rabin, and M. Buban, 2003: Relation of radar-derived kinematic features and in-situ moisture to cumulus development on 24 May 2002 during IHOP. *Preprints, 31st Radar Meteor. Conf.*, Amer. Meteor. Soc., Boston, 796-798.

Peckham, S., R. Wilhelmson, L. Wicker, and C. Ziegler, 2004: Numerical simulation of the interaction between the dryline and horizontal convective rolls. *Mon. Wea. Rev.*, **132**, 1792-1812.

Davis, C., N. Atkins, G. Bryan, W. Cotton, D. Dowell, J. Fritsch, B. Jewett, R. Johns, D. Jorgensen, K. Knupp, W.-C. Lee, G. McFarquhar, R, Przybylinski, R. Rauber, B. Smull, J. Trapp, S. Trier, R. Wakimoto, M. Weisman, and C. Ziegler, 2003: Observations from the Bow Echo and MCV Experiment (BAMEX). *Preprints, 31st Radar Meteor. Conf.*, Amer. Meteor. Soc., Boston, 22-25.

Davis, C., N. Atkins, D. Bartels, L. Bosart, M. Coniglio, G. Bryan, W. Cotton, D. Dowell, B. Jewett, R. Johns, D. Jorgensen, J. Knievel, K. Knupp, W.-C. Lee, G. McFarquhar, J. Moore, R, Przybylinski, R. Rauber, B. Smull, R. Trapp, S. Trier, R. Wakimoto, M. Weisman, and C. Ziegler, 2004: The Bow Echo and MCV Experiment (BAMEX): Observations and opportunities. *Bull. Amer. Meteor. Soc.*, in press.
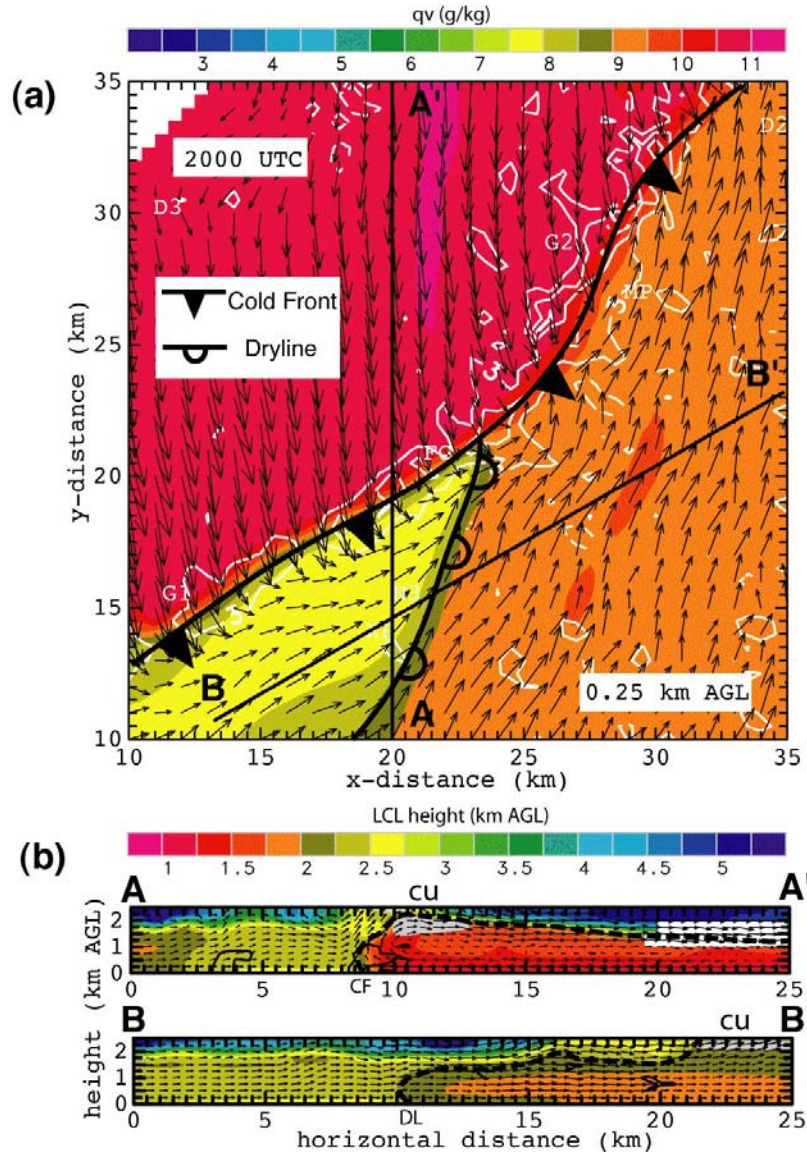
Radar and Lagrangian thermodynamic analysis at 2000 UTC on 24 May 2002 based on IHOP observations. (a) Vector airflow, vertical vorticity (s⁻¹) x 103 (white contours at 3 x 10-3 s⁻¹ interval, solid positive, dashed negative), and (b) analyzed water vapor mix. The 2000 UTC thermodynamic analysis assimilated data and calculated trajectories between 1945 and 2015 UTC and utilized in-situ data from eight mobile mesonets, three mobile sounding vehicles, and two research aircraft. Sharp frontal and dryline moisture gradients are noted (panel a). Lifting of low-LCL air by mesoscale updrafts produces cumulus clouds in the analysis, verifying the primary hypothesis that rising air parcels must achieve their LCL before leaving the mesoscale updraft feeding moisture to their bases. Cloud evaporation commences after saturated air enters weak downdrafts. The cold frontal cumulus entrains air from the lowest 500 m AGL behind the cold front (A-A'). A higher cloud base along the front entrains air from around 1.5 km AGL in the dry boundary layer ahead of the front (A-A'). A cumulus east of the dryline and cold front entrains air from ~1.25 km AGL

Observations and Numerical Simulations of Derecho-Producing Convective Systems
Stensrud, Coniglio, Richman

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Improve our fundamental understanding of the environments and mechanisms responsible for the development and maintenance of widespread severe convective windstorms, known as derechos. This will be accomplished by 1) identifying common large-scale environments associated with the development of derecho-producing convective systems using statistical clustering of a large number of events, and 2) producing a set of horizontally homogeneous cloud-model simulations to determine the mechanisms that help support the longevity of these systems.

Accomplishments
Common large-scale environments associated with the development of derecho-producing convective systems from a large number of events are identified using statistical clustering of the 500-mb geopotential heights as guidance. The majority of the events (72%) fall into three main patterns that include a well-defined upstream trough (40%), a ridge (20%), and a zonal, low-amplitude flow (12%), which is defined as an additional warm-season pattern that is not identified in past studies of derecho environments. Consequently, forecasters need to be aware that the environmental large-scale patterns idealized in past studies only depict a portion of the full spectrum of the possibilities associated with the development of derechos.

To further explore derecho environments, statistics of derecho proximity-sounding parameters are presented relative to the derecho lifecycle as well as relative to the forcing for upward motion for the benefit of forecasters who use ingredients-based techniques. It is found that the environments ahead of maturing derechos tend to moisten at low-levels while remaining relatively dry aloft. In addition, derechos tend to decay as they move into environments with less instability and smaller deep-layer shear. Low-level shear (instability) is found to be significantly higher (lower) for the more strongly forced events, while the low-level storm relative inflow tends to be much deeper for the more weakly forced events. Furthermore, discrepancies are found in both low-level and deep-tropospheric shear parameters between observations and the shear profiles considered favorable for strong, long-lived convective systems in idealized simulations.

To explore the role of upper-level shear in derecho environments, a set of two-dimensional simulations of density currents within a dry, neutrally stable environment are used to examine the ability of a cold pool to lift environmental air within a vertically sheared flow. The results confirm that the addition of upper-level shear to a wind profile with weak to moderate low-level shear increases the vertical displacement of low-level parcels despite a decrease in the vertical velocity along the cold pool interface, as suggested by previous studies. Parcels that are elevated above the surface (1-2 km) overturn and are responsible for the deep lifting in the deep-shear environments. This deep overturning caused by the upper-level shear helps to maintain the tilt of the convective systems in more complex two-dimensional and three dimensional simulations. The overturning also is shown to greatly increase the size of the convective systems in the three-dimensional simulations by facilitating the initiation and maintenance of convective cells along the cold pool. When combined with estimates of the cold pool motion and the storm-relative hodograph, these results may best be used for the prediction of the demise of strong, linear mesoscale convective systems (MCSs) and may provide a conceptual model for the persistence of strong MCSs above a surface nocturnal inversion in situations that are not forced by a low-level jet.

Publications

Coniglio, M.C., D.J. Stensrud, and M.B. Richman, 2004: An observational study of derecho-producing convective systems. *Wea. Forecasting*, **19**, 320-327.

Coniglio, M.C., and D.J. Stensrud, 2004: On the climatology of derechos. *Wea. Forecasting*, **19**, 595-605.
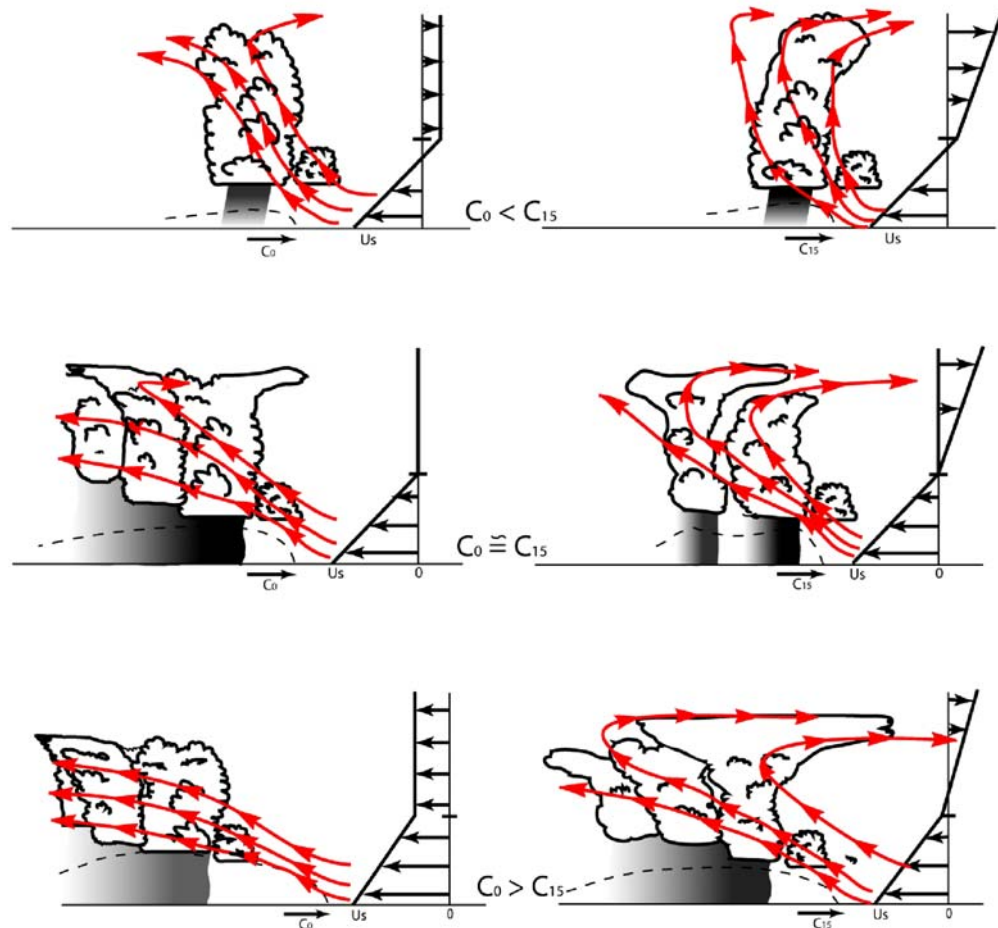
Schematic diagram depicting the relative airflow and the evolution of the convective systems for the case with no upper-level shear (left column) and the case for 15 m s^{-1} of upper-level shear (right column) for the 1-2 h period (top row), the 2-3 h period (middle row), and the 3-4 h period (bottom row). The dashed line represents the cold pool and C0 and C15 represent the cold pool motion for the no shear and 15 m s^{-1} shear cases, respectively. The darker shading represents heavier precipitation rates.

Influence of a Hailstreak on Boundary Layer Evolution

Segele, **Stensrud;** Ratcliffe and Henebry (U. Nebraska)

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives

Examine the limited observational data and explore the effects of the 20 June 1997 hailstreaks on the surrounding environment.

Accomplishments

Severe thunderstorms developed on 20 June 1997 and produced heavy precipitation, damaging winds, and large hail over two swaths in southeastern South Dakota. Calculations of fractional vegetation

coverage (scaled from 0 to 1) based upon composite satellite data indicate that, within the hailstreak region, vegetation coverage decreased from 0.50 to near 0.25 owing to the damaging effects of hail on the growing vegetation. The northern edge of the larger hailstreak was located a few km south of Chamberlain, SD, a NWS surface observation site. Hourly observations from Chamberlain and several nearby surface sites in South Dakota are averaged over 7 days both before and after this hail event. These observations illustrate that the late afternoon (nighttime) temperatures are 2°C higher (2°C lower) near the hailstreak after the event than before the event. Similarly, daily average dewpoint temperatures after the event are 2.6°C lower near the hailstreak. These changes are consistent with the influences of a recently de-vegetated zone on changes to the surface energy budget.

To explore how these hailstreaks further affected the evolution of the planetary boundary layer in this region, two model simulations are performed using the Fifth-Generation Pennsylvania State University-National Center for Atmospheric Research Mesoscale Model (MM5). In the control run, climatology is used for the land surface characteristics and hence the simulation is independent of the hailstreaks. In the hailstreak simulation (HSS), the fractional vegetation coverage and soil moisture in the hailstreak regions are modified to reflect the likely conditions within the hailstreaks. Two different days are simulated, one with low surface wind speeds and one with stronger surface wind speeds. For the low surface wind speed case, the HSS simulation produces a sea-breeze-like circulation in the boundary layer by mid-morning. For the stronger surface wind speed case, this sea-breeze-like circulation does not develop in the HSS, but the simulated low-level temperatures are modified over a larger area. These results suggest that to capture and reasonably simulate the evolution of boundary layer structures, there is a need for routine daily updates of land surface information. Hailstreaks also are important to consider in the future as the focus for observational studies on non-classical mesoscale circulations.

Publications
Segele, Z. T., D. J. Stensrud, I. C. Ratcliffe, and G. M. Henebry, 2004: Influence of a hailstreak on boundary layer evolution. *Mon. Wea. Rev*., submitted.
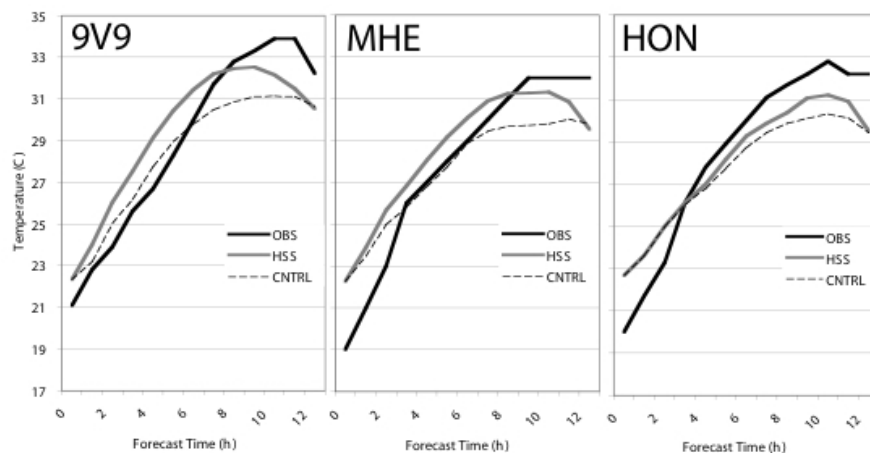
Observed and model simulated 2-m temperatures (°C) plotted versus model simulation time (h) for Chamberlain(9V9), Mitchell (MHE), and Huron (HON), South Dakota, for the control run and HSS beginning 1200 UTC 27 June 1997. Station 9V9 is closest to the hailstreak, followed by MHE and HON. The HSS simulation produces a 0.9-1.6 °C warmer than the control run, with the effect of the hailstreak being greatest for station closest to the hailstreak (9V9). Thus, the addition of the hailstreaks to the model initial condition yields a simulation of 2-m temperature that is closer to the available observations in eastern South Dakota. In addition, the increase in 2-m temperature at 9V9 from the HSS as compared with values from the control run is roughly of the same magnitude as the increase in observed temperature at 9V9 compared to the surrounding surface stations when averaged over 7-days in the period after the hail event. This suggests that the magnitude of the simulated increase in temperature near the hailstreak seen in the HSS appears to be reasonable.

Effects of Multi-Dimensional Radiative Transfer on Cloud System Evolution
Mechem, **Y. Kogan**, and Collaborators

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Assess the importance of horizontal radiative transfer on the evolution of radiatively-forced PBL clouds.

Accomplishments
One-dimensional, two- or four-stream radiative transfer codes commonly used in numerical models neglect horizontal photon transport, which may lead to significant differences in cloud radiative forcing and have important consequences for cloud system evolution. Along with collaborators from Pacific Northwest National Laboratory, the University of Colorado, Florida State University, Los Alamos National Laboratory, and NASA/GSFC, we are exploring the interactive feedback of longwave multi-dimensional (MD) radiative effects on cloud dynamics. Specifically, we have applied the multi-dimensional radiative transfer scheme of Evans (SHDOM; *J. Atmos. Sci.* 1988) to cloud fields produced by large eddy simulation (LES) in order to infer feedbacks onto cloud-topped boundary layer dynamics. We also have coupled SHDOM to the CIMMS LES in order to address the interactive and evolutionary nature of the multi-dimensional radiative effects. The fully interactive MD radiative transfer enables us to evaluate the effect horizontal photon transfer has on cloud system dynamics and evolution.

The MD effect is a strong function of cloud fraction, as shown by radiative transfer calculations of idealized cloud fields (see figure below). In the fully interactive simulations, the longwave MD effect is realized via the manner in which the MD heating rates modify the thermal buoyancy field relative to the 1D solution. This mechanism drives the direct radiative-dynamic feedback of interest. The significant differences in radiative forcing between 1D and MD calculations do not lead to any bias in cloud system evolution, though the limited number of drizzle cells in the domain introduces significant noise in the evolution statistics. In any case, the difference between MD and 1D cloud fractions are of the same magnitude as the cloud fraction from different LES realizations. We have two possible explanations for the small interactive MD effect. First, in high cloud fraction cases the horizontal photon flow may be only a minor contribution to the total forcing. Second, the low cloud fraction regime tends to be associated with boundary layer decoupling and energetics that may be more surface-based and less radiatively driven. Thus, the radiative term becomes a smaller portion of the total forcing. The results indicate that the typical 1D, plane-parallel methods of radiative transfer may be sufficiently accurate for longwave forcing of cloud-topped boundary layer dynamics.

Publications
Mechem, D. B., M. Ovtchinnikov, Y. L. Kogan, K. F. Evans, A. B. Davis, R. F. Cahalan, E. E. Takara, and R. G. Ellingson, 2004: Multi-dimensional effects in longwave radiative forcing of PBL clouds. *Proc. of the Fourteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, 22-26 April 2004, Albuquerque, NM.
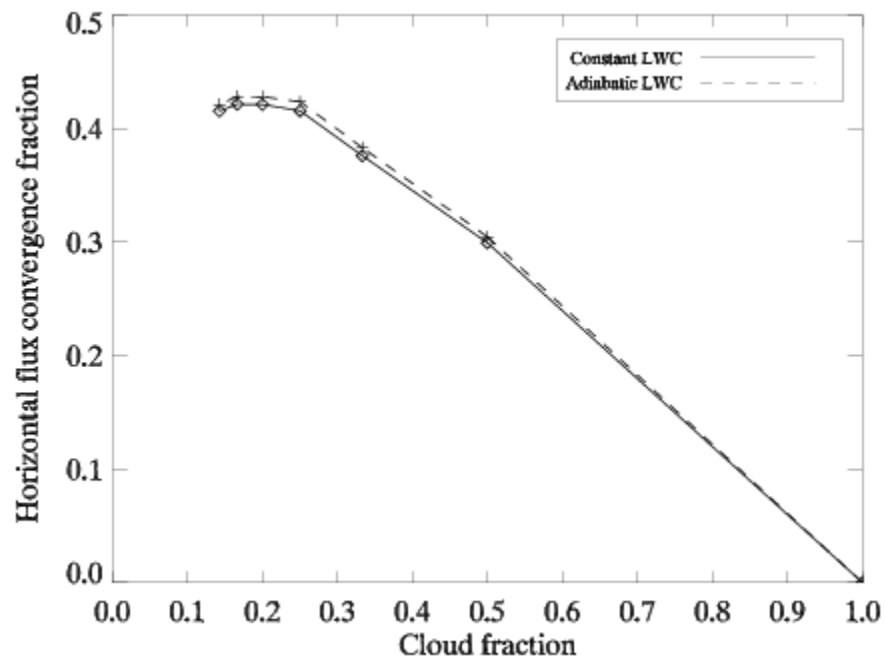
Relative contribution to the total radiative fluxes of the horizontal component as a function of cloud fraction. Longwave MD radiative transfer is calculated for fields of idealized, rectangular clouds of various cloud fraction. The figure shows the relative contribution of the horizontal flux convergence to the total.

Statistical Formulations of Cloud Parameters over the U.S. Southern Great Plains
Z. Kogan, **Mechem**, **Y. Kogan**

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Develop a parameterization of cloud variability for use in climate and numerical weather prediction models.

Accomplishments
The variability of overcast low stratiform clouds observed over the ARM Climate Research Facility Southern Great Plains (ACRF SGP) site has been analyzed. Results from the analysis of approximately 1000 hours of winter season millimeter-wave cloud radar data over the ARM ACRF SGP site show that the behavior of low cloud systems is strongly influenced by the presence of precipitation and how closely the cloud system conforms to the cloud-topped boundary layer paradigm. Low altitude stratiform clouds exhibit on average 40 percent greater variability than canonical boundary layer clouds. Cloud variability dramatically depends on microphysical processes and increases 2-5 times within a typical reflectivity range. The presence of precipitation greatly enhances variability, with drizzling clouds exhibiting 50 percent greater variability than non-precipitating clouds. Variability is a strong function of scale (see figure below) and almost doubles in the 20-100 minute temporal scale range. A frozen turbulence assumption can be employed to transform the temporal scales into spatial.

Parameterizations of subgrid cloud variability are fundamentally important for calculations of unbiased grid mean process rates and accurate radiative fluxes. Parameterizations of subgrid variability, based on probability distribution functions (PDFs) of radar reflectivity, are developed for the two cloud types and

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scales of 10 and 30 km, taken to be representative of mesoscale and large scale model grid sizes, respectively. For these cloud types and scales, the reflectivity PDFs can be accurately approximated by a truncated Gaussian function, specified by the mean and standard deviation. Standard deviation can be reasonably well parameterized as a linear function of the first moment. Errors arising from the use of different analytic PDFs to approximate the full PDF were analyzed. The PDFs of radar reflectivity can be transformed into PDFs of liquid water content for non-precipitating clouds.

Publications

Kogan, Z. N., D. B. Mechem, and Y. L. Kogan, 2004: A parameterization of low stratiform cloud variability based on radar reflectivity data. *J. Geophys. Res.*, submitted.

Kogan, Z. N., D. B. Mechem, and Y. L. Kogan, 2003: Radar study on variability of continental low stratiform clouds. *Preprints, 31st Conference on Radar Meteorology*, 6-12 August 2003, Seattle, WA, Amer. Meteor. Soc.

Kogan, Z. N., D. B. Mechem, and Y. L. Kogan, 2004: Characterizing stratiform cloud variability from Millimeter-Wave Radar Data. *Proc. of the Fourteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, 22-26 April 2004, Albuquerque, NM.
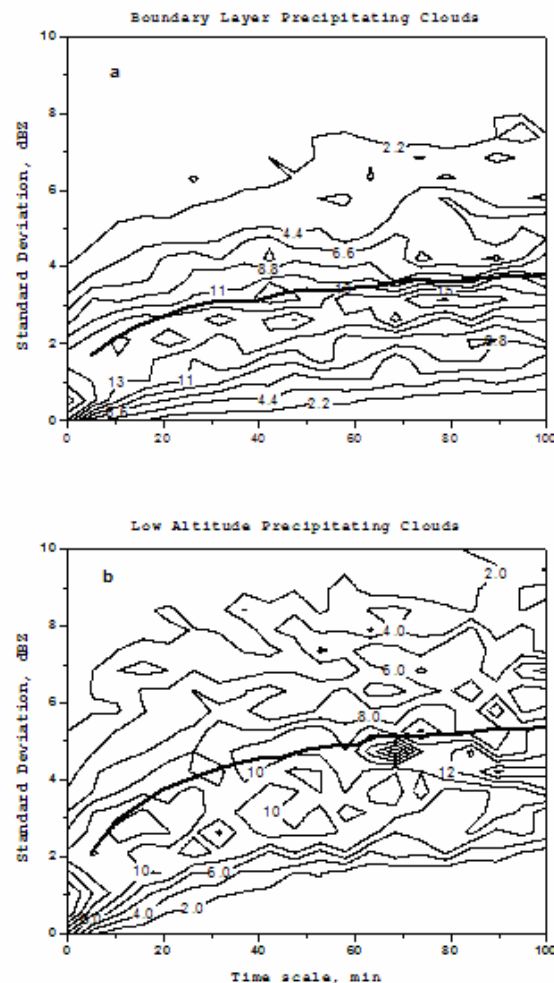
Isopleths (contour interval is 2 percent) of probability distribution function for the standard deviation of reflectivity as a function of scale (sub-segment length) for boundary layer and low altitude cloud categories. The thick solid lines represent the mean standard deviation. This figure illustrates the increase of variability with scale. The greatest scale sensitivity occurs at the smallest scales, between 5 and 30 minutes for BL clouds and between 5 and 60 minutes for LA clouds. This peak in sensitivity may be dictated by physical mechanisms that drive variability on these particular scales.

Parameterization of Cloud Microphysics and Radiation
Y. Kogan

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Understand feedbacks between cloud microphysical, radiative and dynamical processes, and develop cloud and radiation parameterizations for use in numerical weather prediction models.

Accomplishments
Warm Rain Initiation in Stratiform Clouds. During the past year large eddy simulations of stratocumulus clouds were conducted, from which a dataset of 44,800 air parcel trajectories was derived. The analysis showed that the in-cloud residence time of an air parcel is much larger than previously estimated. Namely, depending on boundary layer conditions, an air parcel may spend up to 60-80 min in a cloud, which is 3-5 times longer than the characteristic cloud eddy turnover time. These values are significantly higher than previous estimates of average in-cloud residence time and indicate that recycling is a dominant feature of marine stratocumulus cloud dynamics. Our results also showed the significant spatial variability of in-cloud residence time meaning that air parcels with different "cloud age" coexist and mix on all scales. The examples of such mixing are shown in the figure below which depicts the height-time evolution of air parcels which end in two specific cloud volumes. The top panel shows that most parcels came to this volume in updrafts of different intensities, from 0.3 to over 1 ms^{-1}. There are four parcels that resided in the cloud from 60 to 90 minutes and three parcels with residence time of 30-40 min. The bottom panel shows air parcels which all resided in the cloud for different periods of time. As drizzle drops which are formed in 'old' parcels have larger phase relaxation times, they do not completely evaporate in downdrafts and mix with freshly activated condensation nuclei, thus serving as drizzle embryos. Evidently, this type of mixing between parcels which have dramatically different histories can also contribute to cloud drop spectral broadening. The results of this study have important implications for cloud microstructure formation, drizzle initiation, as well as estimation of aqueous chemical transformation rates.

Study of Drizzle Heterogeneity in a Stratocumulus-topped Boundary Layer. The time and space distributions of drizzle from a stratocumulus-topped marine boundary layer were analyzed using data from large eddy simulations. The heavy drizzle patches (R/Rm > 5.0) can contribute 35 percent to total drizzle mass with only 10 percent of surface area coverage. The corresponding values are 76 and 22 percent for R/Rm > 1.0, respectively. On the other hand, drizzle-free and light drizzle areas (R/Rm < 0.125) cumulatively cover 46 percent of the surface area, but contribute only 3.4 percent to total drizzle. Drizzle intermittency is illustrated by the fact that as many as 10 percent of grid points receive 75 percent of their total drizzle within one quarter of the total time. We also found that spatial distribution of drizzle from marine stratocumuli at different stages of their evolution may be best expressed as a simple function of a normalized drizzle rate. In this case the area coverage fraction can be parameterized by a lognormal function.

Publications
Kogan, Y.L., 2004: Large eddy simulation of recycling in marine stratocumulus clouds. *J. Atmos. Sci*., submitted.
Kogan, Y.L., 2004: Air recycling in boundary layer clouds and its effect on cloud microstructure. *Preprints, 16th Symposium on Boundary Layers and Turbulence*. 9-13 August 2004. Portland, Maine.
Kogan, Y.L., 2004: On the role of large-scale turbulence in cloud microstructure formation. *Preprints, 14th Inter. Conf. on Clouds and Precipitation*, 18-23 July, Bologna, Italy.
Yang, B., and Y. L. Kogan, 2004: On heterogeneity of drizzle in a stratocumulus-topped boundary layer. *Preprints, 14th Inter. Conf. on Clouds and Precipitation*, 18-23 July, Bologna, Italy.
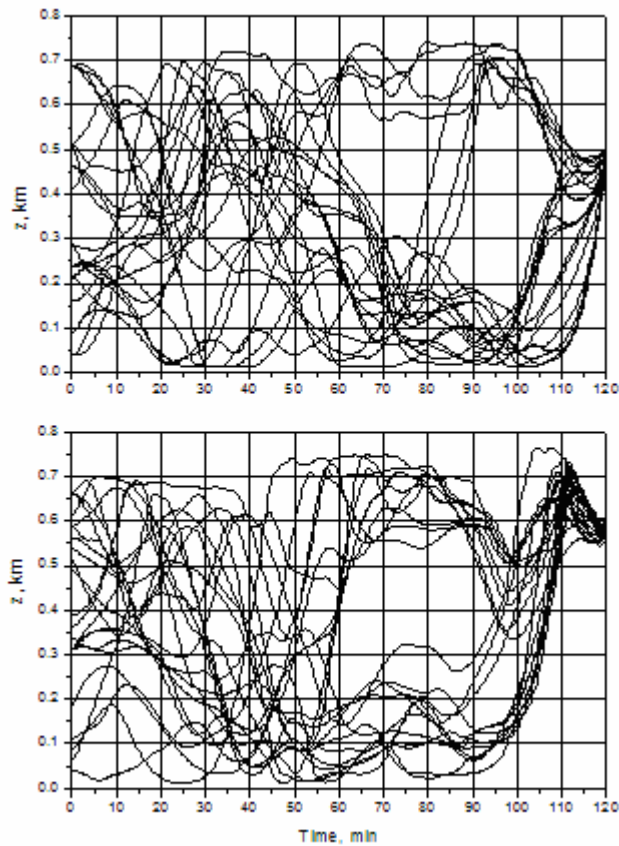
Trajectories of air parcels ending in two air volumes, each 225 x 225 x 50 m³. Cloud base is approximately at 400 m. Mixing between air parcels of different histories will result in spectral broadening and enhanced drizzle formation.

Mesoscale Dynamics
Xu, Gu, Gao, and **NSSL**, NASA, and Institute of Atmospheric Physics (Beijing) Collaborators

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Continue theoretical study on nearly symmetric and nearly baroclinic instabilities in the presence of diffusivity and examine their energetic aspects; study nonlinear oscillations of baroclinic waves caused by mesoscale frontal processes and related vertical motions.

Accomplishments
Nearly Baroclinic Modes.   The structure and energetics of the nearly baroclinic modes are further analyzed in detail. It is shown that the nearly baroclinic modes transport warm air northward with rising motion and transport of cold air southward with sinking motion, so their growth is supported mainly by the baroclinic-type energy conversion. Since the band orientations are not exactly perpendicular to the basic shear, the growth is also assisted by two additional energy conversions: (i) from the basic-state buoyancy through the cross-band horizontal advection to the perturbation buoyancy, and (ii) from the basic-state along-band velocity to the perturbation along-band velocity. When the band orientation is tilted, by nearly 90° or less, to the warm (or cold) side of the basic shear, the two additional energy conversions smoothen (or sharpen) the near-boundary structures and thus reduce (enhance) the effect of diffusive damping,

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especially near the non-slip boundaries. This explains why the baroclinic instability yields to the warm-side tilted, nearly baroclinic instability in the presence of diffusivity.

Nonlinear Oscillations of Eady Baroclinic Waves. Analyses were performed to examine the physical processes involved in nonlinear oscillations of Eady baroclinic waves obtained from viscous semigeostrophic models with two types (free-slip and non-slip) of boundary conditions. By comparing with previous studies for the case of free-slip boundary condition, it is shown that the nonlinear oscillations are produced mainly by the interaction between the baroclinic wave and zonal-mean state (total zonal-mean flow velocity and buoyancy stratification). As the detailed processes are tied up with mesoscale fronts and related vertical motions, the time scale of the nonlinear oscillations is largely controlled by the diffusivity. When the boundary condition is non-slip, the nonlinear oscillations are further damped and slowed by the diffusive process. Since the free-slip (or non-slip) boundary condition is the zero drag (or infinite drag) limit of the more realistic drag boundary condition, the nonlinear oscillations obtained with the two (free-slip and non-slip) types of boundary conditions are two extremes for more realistic nonlinear oscillations.

Publications

Xu, Q., 2003: Nearly symmetric and nearly baroclinic instabilities in the presence of diffusivity. Part I: Growth rate patterns. *J. Fluid Mech.,* **492**, 181-205.

Xu, Q., 2004: Nearly symmetric and nearly baroclinic instabilities in the presence of diffusivity. Part II: Mode structures and energetics. *J. Fluid Mech.,* **500**, 283-312.

Xu, Q., W. Gu, and S. Gao, 2004: Nonlinear oscillations of semigeostrophic Eady waves in the presence of diffusivity. *Adv. Atmos. Sci.*, in press.

Doppler Radar Data Quality Control, Analyses and Assimilation
Xu, **Liu**, **Nai**, **Wang**, **Zhang**, and **NSSL**, NRL, NCEP and Lanzhou University Collaborators

**NOAA Strategic Goal 3** *(Serve Society's Need for Weather and Water Information)*

Objectives
Advance knowledge and skills in storm-scale data assimilation; develop state-of-the-art technologies and software for real-time applications of remotely sensed high-resolution measurements, especially those from Doppler radars, to improve numerical nowcasts and forecasts of severe storms and hazard weather conditions.

Accomplishments
Doppler Radar Data Assimilation. In collaboration with scientists at the Naval Research Laboratory (NRL), a 3.5-dimensional variational (3.5dVar) radar data assimilation package was previously developed for the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). This package has been recently combined with other data fusion technologies to utilize satellite data and surface observations in addition to radar data to improve cloud and precipitation analyses and predictions (Zhao et al. 2003a). The combined package is now being tested for operational applications (Zhao et al. 2003b, 2004) at the NRL. Accompanied with these developments, the 3.5dVar package is also being upgraded in radar data quality control and 3D-wind analysis. In particular, the recently developed three-step dealiasing technique (Gong et al 2003) is used to upgrade the 3.5dVar quality control. A new multivariate scheme was formulated and coded for the 3D-wind analysis in the 3.5dVar. In this scheme, the vector velocity is expressed in terms of stream function and velocity potential and these two scalars (instead of the two velocity components) are used as primary increment variables in the cost function. In addition, the smooth B-spline basis functions (Xu at al. 2001, *Quart. J. Roy. Meteor. Soc.*, **127**, 1053-1067) are used in combination with the NCEP recursive filter to achieve the desired background influences. Numerical experiments are performed to compare the combined filter with the previous univariate filter for individual wind components. The combined filter is found to be effective in achieving the desired background influences and especially in enhancing the desired vertical correlation which improves the wind analysis in data sparse or data void layers.

The upgraded 3.5Var package is incorporated into COAMPS and tested with WSR-88D Level-II data collected from the Oklahoma KTLX radar for the heavy precipitation event on 8 May 2003. The background fields are provided by nested COAMPS runs with resolutions of 54, 18 and 6 km for the coarse, medium and fine grids (all 91x73), respectively. The vertical grid (30 levels) and other parameters are set to be the same as COAMPS operational runs. The control run is initialized at 0000 UTC 8 May 2003. Hourly precipitation fields from the control run are shown in the first figure below for two periods ending at 0700 and 0800 UTC. In comparison with the radar observed reflectivity fields in the second figure below, the predicted precipitation fields are too week and dislocated far from the observed precipitation system. Using the upgraded 3.5DVAR package, three consecutive volume scans (at 0357, 0402, 0407 UTC) of KTLX radar observations are assimilated into the model run at 0400 UTC, and then the test forecast run is launched. Precipitation fields from this test run are plotted in the third figure below for the same two time periods as in the second figure. The improvements are clearly seen in both intensities and overall distributions, although the intensities are still not as strong as the estimated maximum values (nearly 50 mm hr^{-1} in the core areas) from KTLX reflectivity observations. The details are reported in Xu et al. (2004; also see http://gaussian.gcn.ou.edu:8080/presentation.shtm).
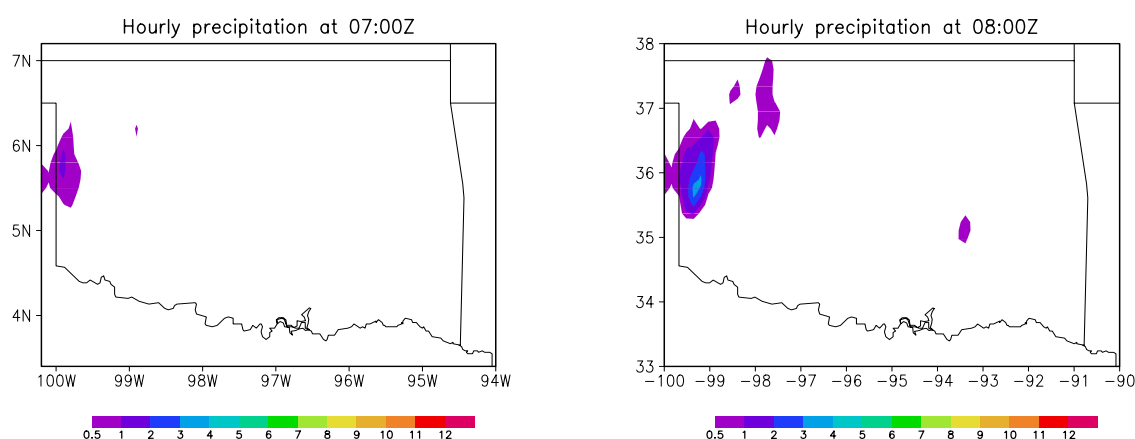
Precipitation fields (mm hr^{-1}) from the control run at 0700 UTC (left) and 0800 UTC (right on 8 May 2003.
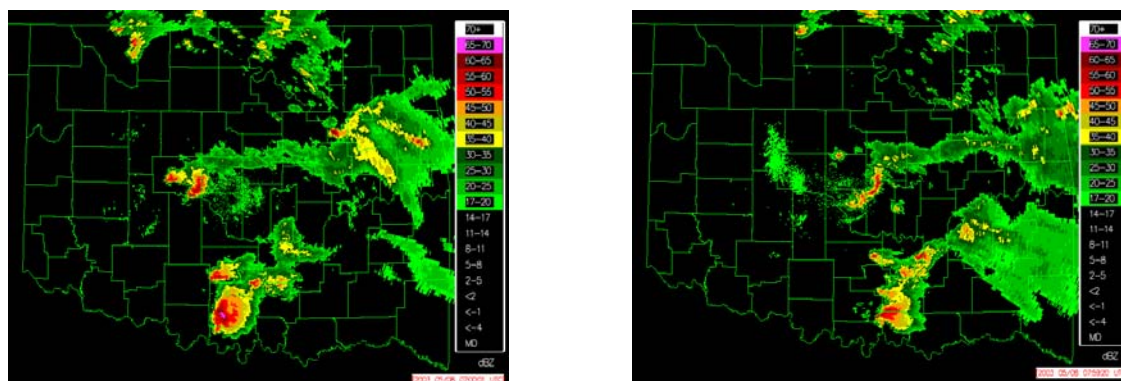
KTLX observed reflectivity fields on 1.5° tilt at 0700 UTC (left) and 0800 UTC (right) on 8 May 2003.

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| Hourly precipitation at 07:00Z | Hourly precipitation at 08:00Z |
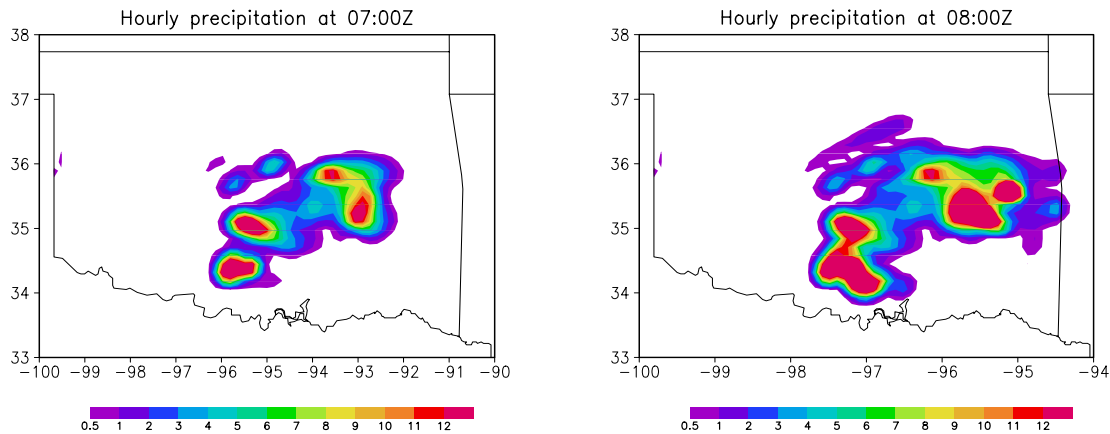
As in the first figure above, but from the test run with radar data.

An Improved Method for Doppler Wind Analysis and Thermodynamic Retrievals. A temporal interpolation is required for three-dimensional Doppler wind analyses and thermodynamic retrievals when the precise measurement time is counted for each radar beam position. Traditionally, the time interpolation is done by a linear scheme either in the measurement space or in the analysis space. Since a volume scan often takes 5–10 minutes, the linear time interpolation is not accurate enough to capture the rapidly-changing winds associated with a fast moving and fast growing storm. Performing the linear interpolation in a frame moving with the storm can reduce the error, but the analyzed and retrieved fields are traditionally assumed to be stationary in the moving frame. The stationary assumption simplifies the computation but ignores the time variation of the true wind field in the moving frame. By incorporating a linear time interpolation into the moving frame analysis, an improved scheme is developed. The merits of the new scheme are demonstrated by idealized examples and numerical experiments with simulated radar observations. The new scheme is also applied to real radar data for a supercell storm.

Doppler Radar Data Quality Control. Radar echoes from migrating birds can severely contaminate Doppler velocity measurements. For meteorological applications, especially quantitative applications in radar data assimilation, it is necessary to remove bird-contaminated velocity scans by using an automated identification technique. Such a technique is developed in two steps: (i) extract main features of migrating-bird echoes from Doppler velocity imageries and find proper parameters to quantify these features; and (ii) utilize these parameters to develop an automated quality control procedure to identify and flag migrating-bird contaminated velocity scans (sweeps). The first step is accomplished in this study by analyzing migrating-bird echoes in the Level II data collected from the Oklahoma KTLX radar during the 2003 spring migrating season. The analyzed echoes and contaminated velocities are further verified by polarimetric radar measurements from the NSSL KOUN radar, GOES IR images, and rawinsonde measurements. Three proper parameters are found and their histograms were prepared for the second step of development.

Publications

Gong, J., L. Wang, and Q. Xu, 2003: A three-step dealiasing method for Doppler velocity data quality control. *J. Atmos. & Oceanic Technol.,* **20**, 1738-1748.

Xu, Q., L. Wang, P. Zhang, S. Liu, Q. Zhao, K. Sashegyi, and J. Nachamkin, 2004: Progress in radar data quality control and assimilation. *Sixth International Symposium of Hydrological Applications of Weather Radar,* 2-4 February 2004, Melbourne, Australia, Bureau of Meteorology & Australian Meteor. Oceanographic Soc., conference CD.

Zhao, Q., J. Cook, Q. Xu, P. Harasti, and M, Frost, 2004: Assimilating radar-observed winds into a high-resolution numerical weather analysis and prediction system at NRL. *Sixth International Symposium of Hydrological Applications of Weather Radar,* 2-4 February 2004, Melbourne, Australia, Bureau of Meteorology & Australian Meteor. Oceanographic Soc.**,** conference CD.

Liu, S., C. Qiu, Q. Xu, P. Zhang, and A. Shao, 2004: An improved method for Doppler wind and thermodynamic retrievals. *Adv. Atmos. Sci.*, **22**, 329-336.

Liu, S., C. Qiu, Q. Xu, and P. Zhang, 2004: An improved time interpolation for three-dimensional Doppler wind analysis. *J. Appl. Meteor.*, accepted.

Zhang, P., S. Liu, and Q. Xu, 2004: Quality control of Doppler velocities contaminated by migrating birds. Part I: Feature extraction and quality control parameters. *J. Atmos. & Oceanic Technol.*, submitted.

Estimating Soil Water Content from Soil Temperature Measurements
Xu, Zhou, S. Zhang, Qiu, and **NSSL**, NCEP and Lanzhou University Collaborators

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Advance knowledge and skills in surface and soil data assimilation; develop state-of-art techniques for applications of ARM Program and Oklahoma Mesonet surface and soil data.

Accomplishments
A prototype method was developed by using the linear regression to retrieve daily averaged soil water content from diurnal variations of soil temperature measured at three or more depths. The method was then upgraded by using an advanced technique based on the adaptive Kalman filter. In this method, the soil water contents are estimated as control variables that regulate the variations of soil temperatures at different depths and make the model non-biased, while the model system noise covariance matrix is estimated by the covariance-matching technique. The method is tested with soil temperature data collected during 1-31 July 2000 from the ARM soil water and temperature system at the Lamont Central Facility (see figure below). The estimated soil water contents were verified against the observed values and the root mean square differences were found to be small. (see http://gaussian.gcn.ou.edu:8080/newpub.shtm).

Publications
Xu, Q., and B. Zhou, 2003: Retrieving soil moisture from soil temperature measurements by using linear regression. *Adv. Atmos. Sci.*, **20**, 849-858.
Zhang, S. W., C. J. Qiu, and Q. Xu, 2004: Estimating soil water contents from soil temperature measurements by using adaptive Kalman filter. *J. Appl. Meteor.*, **43**, 379-389.
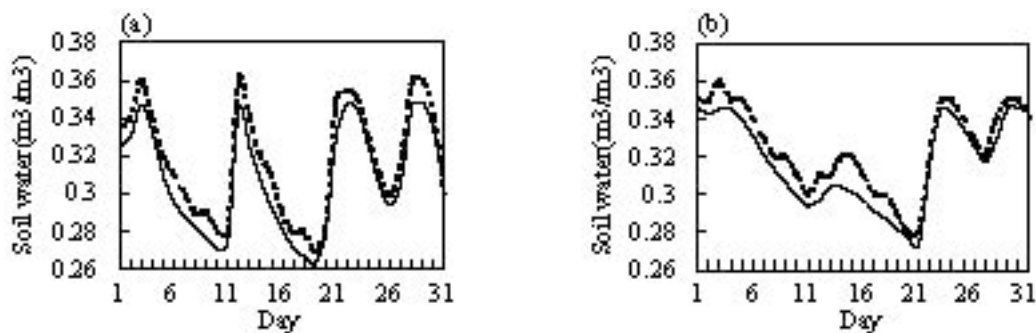
Comparisons between the estimated (shaded) and directly measured (solid) soil volumetric water contents at depths of 5 cm (left) and 15 cm (right) for the east profile of the ARM Central Facility soil water and temperature system.

Studies on Deep Convection, Synoptic Scale Controls on Tornado Outbreaks, and Supercell Storm Motion
Doswell, Weber, Thompson, Hart, Crosbie, Edwards, **Ramsay**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Determine how environmental factors, notably the forcing that initiates deep convection and the environmental wind and thermodynamic profiles, control the time-dependent behavior of deep convective storms; collect and categorize past synoptic scale tornado outbreak events; estimate supercell storm motion using hodographs.

Accomplishments

Numerical Modeling Study of the Time-Dependent Behavior of Convection. This work involves the use of a 3D cloud model (based on the ARPS model), developed by Dr. Daniel Weber. The goal is to determine how environmental factors, notably the forcing that initiates deep convection and the environmental wind and thermodynamic profiles, control the time-dependent behavior of deep convective storms. Early simulation study results can be viewed at http://www.caps.ou.edu/~dweber/bubbles.html. As anticipated, we have been able to produce simulations using parameterized thermal forcing that strongly resemble observed isolated multicell convective storms.   We are developing algorithms for parameterized momentum forcing and for identifying and diagnosing the presence of "bubbles" within a convective simulation

Evaluation of Synoptic-Scale Controls on Tornado Outbreaks. An important tornado forecasting problem is whether or not a particular synoptic-scale system is going to produce a significant outbreak of tornadoes. Although much work has been done on individual case studies over the decades since tornado forecasting began in the 1950s, this issue remains problematic for forecasters. In collaboration with Mr. Richard Thompson, Mr. John Hart, Mr. Casey Crosbie, and Mr. Roger Edwards of the Storm Prediction Center, an effort is underway to collect and categorize past events and build a database for the study. Work continues on the project.

Hodograph-Based Supercell Storm Motion Estimates. A project to estimate supercell storm motion using hodographs has been carried out, with the idea being to do a comprehensive examination of the sensitivity to the essentially arbitrary choices of levels for a number of commonly-used schemes (see figure below). The work has been completed and Mr. Hamish Ramsay has completed his M.S. thesis on the topic.

Publications

Doswell, C.A. III, and J.S. Evans, 2003: Proximity sounding analysis for derechos and supercells – An assessment of similarities and differences. *Atmos. Res.*, **58**, 117-133.

Doswell, C.A. III, 2003: Societal impacts of severe thunderstorms and tornadoes: Lessons learned and implications for Europe. *Atmos Res*., **58**, 135-152.

Doswell, C.A. III, and P.M. Markowski, 2004: Is buoyancy a relative quantity? *Mon. Wea. Rev*., **132**, 853-863.

Setvák, M., R.M. Rabin, C.A. Doswell III, and V. Levizzani, 2003: Satellite observations of convective storm top features in the 1.6 and 3.7/3.9 μm spectral bands. *Atmos. Res.,* **58**, 607-627.

Brooks, H.E., C.A. Doswell III and M. Kay, 2003: Climatological estimates of local daily tornado probability for the United States. *Wea. Forecasting*, **18**, 626-640.
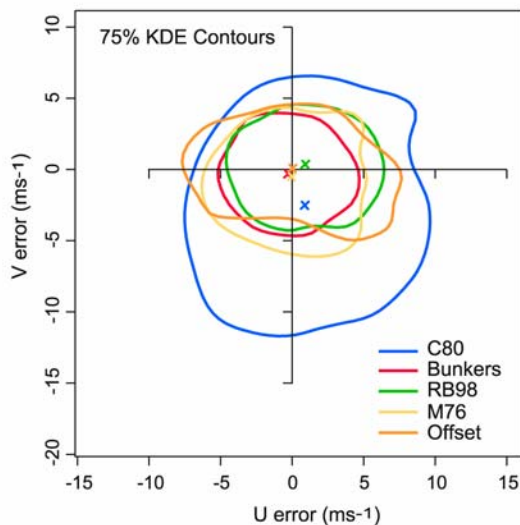
Figure showing the 75% kernel density estimation (KDE) contour for each of 5 different supercell motion estimation schemes, based on a sample of 394 cases. The smaller the area enclosed, the smaller the dispersion of the estimates about the actual motion, and the more nearly centered the contour is, the smaller the bias in the estimates.

Vertical Vortices in the Convective Boundary Layer
Kanak, **Lilly**, **Snow**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Identify the dynamical mechanisms of vertical vortex formation in the convective boundary layer and assess the role of these vertical vortices on boundary layer processes.

Accomplishments
Quiescent Environments. Three-dimensional, two-meter resolution boundary layer large eddy simulations (LESs) have been conducted, the results of which exhibit vertical vortices with dust devil-scale motions. This is likely the first LES to resolve and simulate vertical vortices with dust devil characteristics. The vortices' structure and intensity are compared to those of dust devil field observations by Sinclair and others. The latest results (2 m and 6 m resolution simulations) show that vertical vortices often form in a bookend vortex pattern with pairs of counter-rotating vortices. This structure implies that asymmetries in the convective cell pattern may be responsible for local horizontal jets, which are associated with local horizontal wind shears. These may be a source of vertical vorticity for the dust devil-like vortices. It also appears that many vortices have quite asymmetric structure, with much stronger winds on one side of the vortex than the other. Similarly, the maximum updraft and minimum pressure centers are often offset from the center of the circulations. Preliminary analysis of terms of the vertical vorticity budget suggest that tilting terms are significant on one side of the vortex (where the wind speeds are greatest), and the stretching terms are relatively small in association with established vortices. In addition, it is shown that the eddy mixing coefficient is minimized in the center of vertical vortices (see figure below).

Environments with Ambient Wind Shears. Experiments to extend the LES results to consider the effects of ambient winds and wind shears on these vortices have been carried out. These results imply that the presence of environmental wind appears to inhibit the formation of vertical vortices as compared with the case of a quiescent environment. Further analyses are planned.

Publications
Kanak, K. M. 2004: Numerical simulation of dust devil-scale vortices. *Quart. J. Roy. Meteor. Soc.*, accepted.
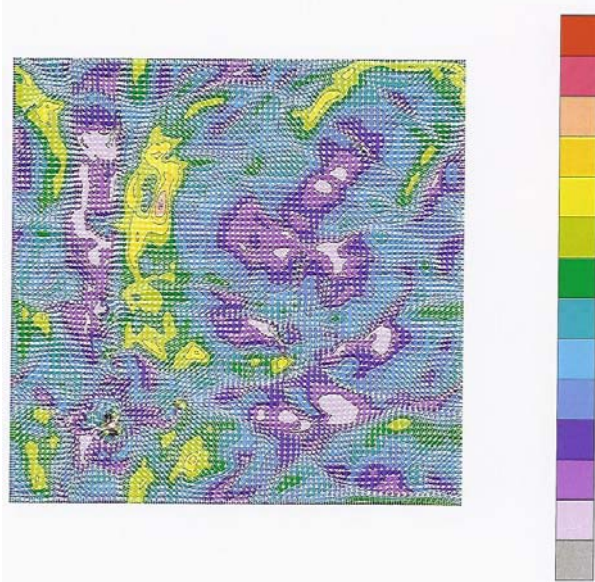
Cross-section of eddy mixing coefficient (shaded) and horizontal velocity vectors (white arrows). Results are from the LES with 6 m horizontal resolution at z = 3 m and t = 1930 s. Color shading is Km: 0.11(grey) to 1.51 (red) by 0.1 m^2 s^{-1}. White vectors are horizontal velocity vectors: the maximum vector is 5.6 m s^{-1}. A pair of counter-rotating vortices is shown in which Km is minimized in the vortex centers and maximized between them.

Martian Dust Devils
Cantor, **Kanak**, Edgett

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Analyze Martian dust devil characteristics as determined by Mars Orbiter Camera (MOC) images and make comparisons with terrestrial dust devils; gain insight into dust devil formation and maintenance dynamics, and their role in boundary layer processes, by comparison of their characteristics in two different atmospheres.

Accomplishments
Collaborative efforts with Dr. Ken Edgett and Dr. Bruce Cantor at Malin Space Science Systems (MSSS) have resulted in a paper on Martian dust devils being submitted to Geophysical Research Letters. In this paper, observations of dust devils and dust devil tracks from Mars Orbiter Camera images are described. Recent data from the Mars Rover Thermal Emission Spectrometer are used to determine a representative temperature profile that might be typical of Martian dust devil environments in order to make estimates of tangential wind speeds given the physical dimensions determined from the MOC images. Discussions of the ubiquitous dust devil tracks that mark the Martian surface are also presented (see figure below). A second paper is in preparation in which theoretical vortex models are evaluated using the available observational data from Martian dust devils. In addition, LES of the Martian boundary layer are being conducted and the results are anticipated to be included in the second paper.

Publications
Cantor, B. A., K. M. Kanak, and K. E. Edgett, 2005: Mars Orbiter Camera 1997-2004 Observations of Martian Dust Devils. *Geophys. Res. Lett*., to be submitted.
Kanak, K. M., K. E. Edgett, and B. A. Cantor, 2005: Martian Dust Devil Observations and Comparison with Theoretical Vortex Models. *J. Geophys. Res.-Planets*, to be submitted.
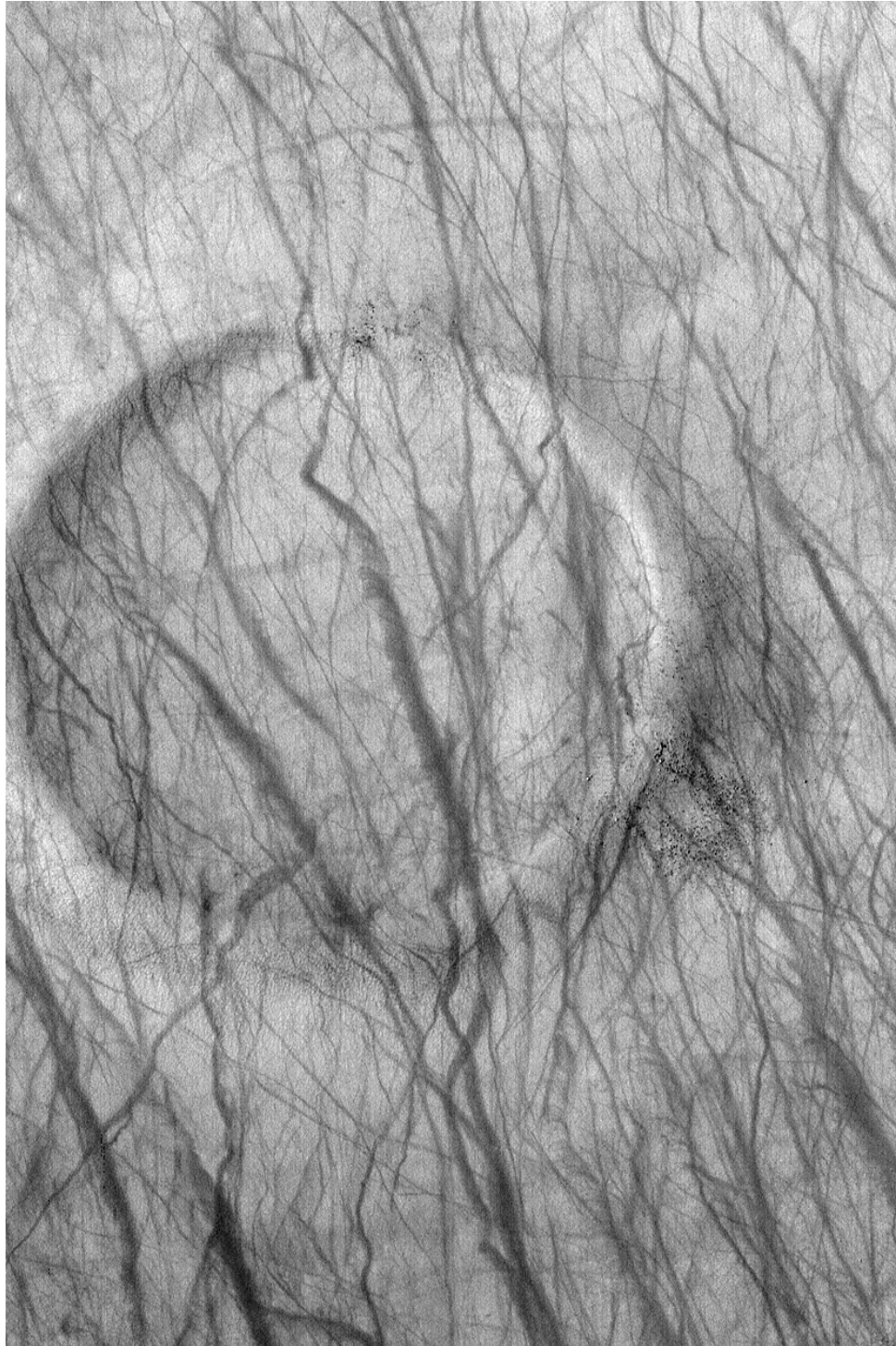
MOC/MGS images and caption courtesy of NASA/JPL/Malin Space Science Systems. This September 2003 Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) image shows a plethora of dark streaks created during the recent southern spring by dust devils as they passed over and around an old, nearly filled, meteor impact crater. The circular feature is the former crater; the dark dots and specks on its rims are boulders. Dust devils create streaks by removing or disrupting thin coatings of fine, bright, dust on the surface. These are ephemeral features that will disappear before the next spring arrives in 2005. The crater is located near 57.4°S, 234.0°W. The image covers an area 3 km (1.9 mi) wide and is illuminated from the upper left.

Atmospheric Turbulence and Mesoscale Meteorology – *Doug Lilly Symposium and Book*
Fedorovich, Rotunno, Stevens, Moeng, **Kanak**, and Collaborators

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
To honor Doug Lilly with a Symposium and the compilation of a book containing papers on areas of research in which he had significant influence.

Accomplishments
K. Kanak and E. Fedorovich were members of the planning committee (which included C.-H. Moeng, D. Lenschow, R. Rotunno, and B. Stevens) for the Geophysical Turbulence Program (GTP) Symposium on "Atmospheric Turbulence and Mesoscale Meteorology", held 14-15 June 2004 at the NCAR Mesa Laboratory to honor CIMMS Fellow Douglas K. Lilly. Along with many others, Kanak contributed to a book of the same title, edited by Fedorovich, Rotunno and Stevens. She authored the first chapter, which is a scientific biography of Lilly with recollections from his colleagues, and prepared the two appendices of the book. Kanak was also a moderator at the Symposium, helped to prepare the meeting program pamphlet, and presented a talk on "Atmospheric Vertical Vortices".

Publications
Kanak, K. M. 2004: Douglas K. Lilly: A Biography, with recollections from K. Bryan, J. Deardorff, K. Droegemeier, J. Kimpel, P. Lamb, D. Lenschow, and J. Smagorinsky. *Atmospheric Turbulence and Mesoscale Meteorology*. Eds. E. Fedorovich, R. Rotunno, and B. Stevens, Cambridge University Press, Cambridge. ISBN: 0521835887, 240 pp.

Idealized Convection
Kanak, **Shapiro**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Examine the formation of vertical vortices within idealized ellipsoidal convective elements in quiescent ambient flows, and explore the effects of ambient winds, stratification, multiple convective elements, and other variables on the formation of these vortices.

Accomplishments
The work presented in Shapiro and Kanak (2002) is extended to explore other variables including the effects of ambient wind on the formation of vertical vortices in ellipsoidal thermal elements. A numerical simulation, with all factors held constant from the previously published results, except for the addition of ambient wind, has been completed and is awaiting analysis. A new manuscript describing a suite of experiments with varying wind and wind shears, as well as other variables, is anticipated.

Evaluations of Microphysical Parameterizations
Straka, **Gilmore**, **Kanak**, **Rasmussen**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Explore the consistency of certain microphysical parameterizations with the physical processes they are designed to represent.

Accomplishments
The equations that represent two microphysical processes, for which total number concentration (N_t) should be conserved, are integrated over sizes of hydrometeor diameters (D) for one- and two-moment methods. The gamma distribution function is assumed and incorporates total mixing ratio q, N_t, and

mean diameter, D_n, (inverse of the distribution slope I). In all of the methods, the slope intercept (n_o), is diagnosed or specified but not predicted. The moment methods explored include:

- The one-moment method where q is predicted, n_o is specified, and N_t and D_n are diagnosed,
- The one-moment method where q is predicted, D_n is specified, and N_t and n_o are diagnosed,
- The two-moment method where q and N_t are predicted, and n_o and D_n are diagnosed, and
- The two-moment method where q and D_n are predicted, and N_t and n_o are diagnosed.

To more easily discern the strengths and weaknesses of each moment-method, two processes are considered: vapor diffusional growth and continuous collection growth, and in both cases there is no introduction of new particles ($dN_t/Dt = 0$). It is demonstrated for the processes examined that all of the schemes fail to conserve N_t and have other unphysical attributes, except the two-moment method where q and N_t are predicted.

Publications

Straka, J., M. S. Gilmore, K. M. Kanak and E. N. Rasmussen: A comparison of conservation properties of microphysical parameterizations: Part 1. Continuous Gamma distribution function with fixed shape parameter. *J. Appl. Meteor.*, accepted.

Straka, J., M. S. Gilmore, E. N. Rasmussen, and K. M. Kanak, 2004: A comparison of conservation properties of microphysical parameterizations: Continuous Gamma distribution function with fixed shape parameter. *Preprints, Fourteenth International Conference on Clouds and Precipitation*, July 19-23, Bologna, Italy.

Thunderstorm Outflow Anvil Dynamics and Mammatus
Schultz, **Kanak**, **Straka**, Trapp, Garrett, Gordon, **Kastner-Klein**, **Zrnic**, **Lilly**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Investigate the dynamics and microphysics of cirrus outflow anvils, isolate the conditions under which mammatus clouds form and are detectable, and make case studies of mammatus events and null events to help assess the role of dynamical and microphysical processes in mammatus cloud formation.

Accomplishments
Numerical simulations of thunderstorm outflow anvils are being planned. A review paper of mammatus clouds is in preparation. Observations, formation theories, and numerical simulation results, relevant to mammatus are presented and discussed. Observations of mammatus reported in the literature range from early aircraft penetration and visual observations from the 1940s, to recent polarimetric radar data. Formation theories remain speculative as mammatus clouds typically exist on short times scales and are thus difficult to measure. In addition, because they are benign entities, the observations that have been obtained have been mostly serendipitous, or tangential to other field program objectives. The plausibility of various theories is evaluated in light of the more recent observations, limited numerical simulations, and some new proximity soundings. Although mammatus are rarely studied, they remain an enigma and an intriguing problem of basic atmospheric fluid dynamics. It is hoped that this paper will summarize the current state of knowledge of the microphysics and dynamics of mammatus clouds and the environments in which they form, and motivate others to study mammatus.

Publications

Schultz, D. M., K. M. Kanak, J. M. Straka, R. J. Trapp, T. J. Garrett, B. A. Gordon, P. M. Kastner-Klein, D. S., Zrnic and D. K. Lilly, 2005: Mounds of mysteries about Mammatus. *Mon. Wea. Rev.*, to be submitted.

Forecast Improvements

WDTB: Warning Decision-Making Research and Training – *Warning Decision-Making Analysis and Training*
Hoggard, N. Levit, Magsig, Mohamad Said, Morris, Schlatter, Wood, Yu, NWS/WDTB collaborators

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Investigate warning decision making issues with NWS forecasters; evoke a better understanding of the warning decision making process; transfer that knowledge to warning decision makers to improve performance

Accomplishments
Warning decision-making analysis continues to be an area of active collaborative research between CIMMS and the NWS Warning Decision Training Branch (WDTB). CIMMS staff has been involved in WDTB training and research of warning decision making for WSR-88D operations, severe weather (including flash flooding), and winter weather. WDTB training is provided to both novices and experts in warning issuance. Hence, a wide variety of participants shared knowledge and experience to test new experimental techniques for issuing and evaluating warnings. A Level III follow-up evaluation of the winter weather workshop indicates that the research and experiences of that particular training have been particularly valuable to NWS forecasters in positively impacting their job performance.

This collaborative work has resulted in other warning decision-making progress. As part of the Advanced Warning and Operations Course (AWOC), CIMMS staff collaborated with WDTB instructors to develop training content on several warning decision-making issues, including data quality issues and recent CIMMS research progress on flash flooding supercells and other severe storms. In addition to the collaboration in content development, CIMMS staff also developed the WDTB Research and Training (WRAT) laboratory for dual-use as a training and research facility. Warning decision-making research previously conducted during workshops at the COMET facility in Boulder, CO, now can be conducted in the operationally representative workstations of the WRAT lab. When training workshops are not in session, the WRAT lab will provide a facility for CIMMS staff to conduct collaborative applied research with WDTB instructors and other scientists in the Norman Weather Center community.

Publications
Levit, N. L., X. Yu, K. R. Hoggard, and N. A. Mohamad Said, 2004: Introducing the WDTB Research and Training (WRAT) Lab: Motivation, design, and configuration. *Proc., National Weather Association Annual Meeting*, Portland, OR.
Yu, X., N. L. Levit, K. R. Hoggard, and N. A. Mohamad Said, 2005: Experiences towards advanced weather research and training. *Preprints, 21st International Conference on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology,* Amer. Meteor. Soc., San Diego.
Grant, B. N., E. Mahoney, A. C. Wood, J. G. LaDue, and X. Yu, 2004: The Winter Weather Warning Decision-Making (WDM) workshops. *Preprints, 20th Conf. On Weather Analysis and Forecasting*, Seattle, WA. Amer. Meteor. Soc.

Simulation from the WRAT lab during a recent AWOC workshop. The WRAT lab allows up to 25 people to work at their own individual workstation during a simulation. The lab's configuration is flexible, allowing participants to work individually or in teams on warning decision-making. Groups can even act as different "forecast offices" and work on interoffice coordination issues.

WDTB: Warning Decision-Making Research and Training – *Warning-Related Forecast Applications*
Bunkers, Hoggard, LaDue, N. Levit, Magsig, Mohamad Said, Morris, Schlatter, Yu

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop applications to improve forecaster knowledge of warning-related issues.

Accomplishments
The warning decision making process is multi-faceted, often being improved directly by analysis tools or data analysis techniques. CIMMS staff has developed some applications to apply these new tools and techniques into the operational forecasting, training, and research environment. One application developed to help improve warning-related forecasts is the HDA/VIL Algorithm Toolkit. This web application calculates WSR-88D Hail Detection Algorithm (HDA) and Vertically Integrated Liquid (VIL) product output and was developed to enable forecasters to better understand how differing reflectivity profiles in a storm affect algorithm output and their diagnosis of large hail.

Another application developed, Sounding Toolkit 1.3, is an updated sounding analysis program. The new functionality in this application gives operational forecasters more flexibility to generate new convective parameters using D2D (AWIPS display software), allowing for the application of newly developed forecast techniques.

Publications

HDA/VIL Algorithm Toolkit: http://www.wdtb.noaa.gov/courses/awoc/ICSvr3/hda_vil_tool.html
Sounding Toolkit 1.3: http://140.90.90.253/~applications/LAD/generalappinfoout.php3?appnum=1050

The interface for the Sounding Toolkit 1.3. This application allows user to view a variety of sounding parameters calculated using several different parcels for different model output.

WDTB: Warning Decision-Making Research and Training – *Warning-Related Forecast Improvements*
Davis, LaDue, Magsig, Schlatter

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Improve our understanding of warning-related issues.

Accomplishments
The warning decision making process is multi-faceted, often being improved directly by unique observing systems, data analysis techniques, human factors, or improvements in forecast verification. Progress is being made in warning-related forecast improvements with the application of unique radar sensors and new data analysis techniques in the following areas:

- The high resolution radar imagery from two Doppler of Wheels (DOW) radars have been used to illustrate the detailed structure and evolution of the hook echo and low level rotation in a tornadic storm. The data show that augmentation of horizontal vorticity that was tilted by the updraft to produce low-level rotation occurred as the accelerated inflow from the supercell updraft moved over an outflow boundary from a neighboring storm.
- Ongoing research on non-meteorological impacts on warning verification shows that population density, while not affecting verification statistics, does impact the number of events observed in an area. Time of day was found to have an impact on verification statistics, but the impact varied depending upon the region.
- A study examining a unique feature associated with non-tornadic supercell, labeled a Zdr hook. Identifying the Zdr hook in association with the mesocyclone in turn will allow forecasters more lead time for hail threat and storm severity. This work could have a significant impact on operational warning decision-making with dual-polarimetric radar implementation expected on all WSR-88Ds within the next 5-7 years.

Publications
Magsig, M.A. and D.C. Dowell, 2004: Evolution of the hook echo and low-level rotation in the 17 May 2000 Brady, NE supercell, *Preprints 22nd Conf. on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc.

Davis, S. M., and J. G. LaDue, 2004: Non-meteorological factors in warning verification. *Preprints, 22nd Conference on Severe Local Storms (SLS)*, Hyannis, MA. Amer. Meteor. Soc.

Schlatter, P.T., J.M. Straka, D. Zrnic, and A. Detwiler, 2004: A unique Zdr feature associated with a mesocyclone and reflectivity appendage. *J. Appl. Meteor.,* submitted.

6/22/95   [172757:172829@172813] Z_{DR} (dB) + Z_{HH} (dBZ)   HEIGHT=2.5 km
T28 Track: [172757:172829@172813]
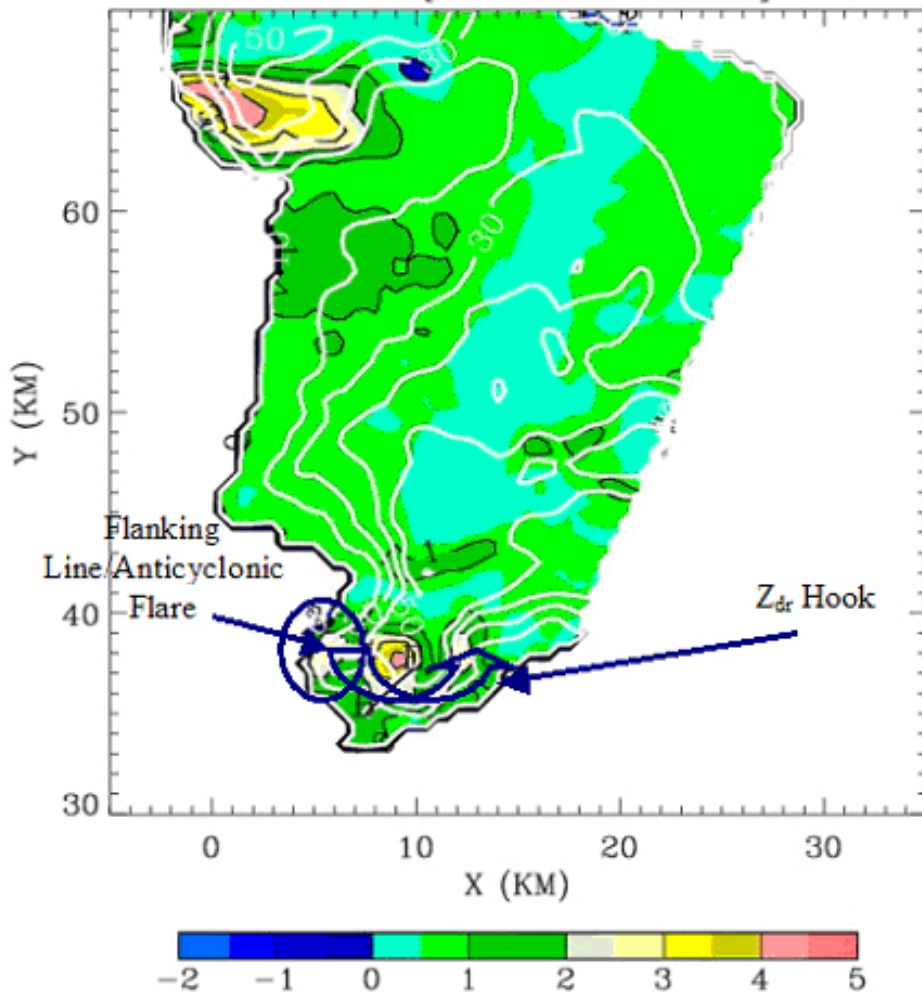
Adapted from Schlatter et al. (2004), this figure illustrates the Zdr hook in a supercell studied from northern Colorado on 22 June 1995. The Zdr hook is a feature associated with hail-producing, non-tornadic supercells. With dual-polarization radar due to be available in operational radars in the next 5-7 years, signatures like this one may be very helpful at distinguishing the hail threat and storm intensity at greater lead times.

WDTB: Warning Decision-Making Research and Training – *Warning Simulation*
Hoggard, N. Levit, Magsig, Mahoney, Mohamad Said, Morris, Rozumalski, Schlatter, Wood, Yu

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop simulation capabilities to enhance warning decision making research and training.

Accomplishments
Simulation development continues to be an active area of research and collaboration. CIMMS scientists collaborated with WDTB and the Forecast Systems Laboratory (FSL) scientists on a project to develop an Informix-free version of the warning component of the Advanced Weather Interactive Processing System (AWIPS) to be used in the Weather Event Simulator (WES). This has allowed for the release of a cost-

free version of WES for public use, and it has provided easy access to the CIMMS simulation capability for the warning community and academic community nationwide. Other AWIPS functionality was added to the WES to enhance simulation research and training, including the Flash Flood Monitoring and Prediction System (FFMP) and recent operational builds of AWIPS. Simulation capabilities have been further enhanced with the development of the WES Scripting Language (WESSL). WESSL provides for the creation of maps and the timed release of images and queries during a simulation to enhance the effectiveness of simulations.

In addition to the updates to WES, several simulation guides were also prepared focusing on a variety of warning forecast topics. Two simulations, focusing on flash flooding and winter weather warning decision-making issues, were released through collaboration with the Science & Training Resource Center at COMET. Four additional simulations were prepared for use during the Advanced Warning Operations Course (AWOC) conducted in August-September 2004 at WDTB. These events were researched and specifically chosen to highlight the storm environment, storm structure, data quality, and other warning decision-making issues that impact the event. The learning objectives of the simulations are correlated with the course as a whole.

Publications

Magsig, M. A., 2004: Expanding Weather Event Simulator capabilities for National Weather Service training, *Preprints, 20th International Conference on Interactive Information and Processing Systems (IIPS)*, 12-15 January 2004, Seattle, WA. Amer. Meteor. Soc.

Magsig, M.A., N. A. Said, X. Yu, and N. L. Levit, 2004: The Weather Event Simulator and opportunities for the severe storms community, *Preprints 22nd Conf. on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc. 4-8 Oct, 2004.
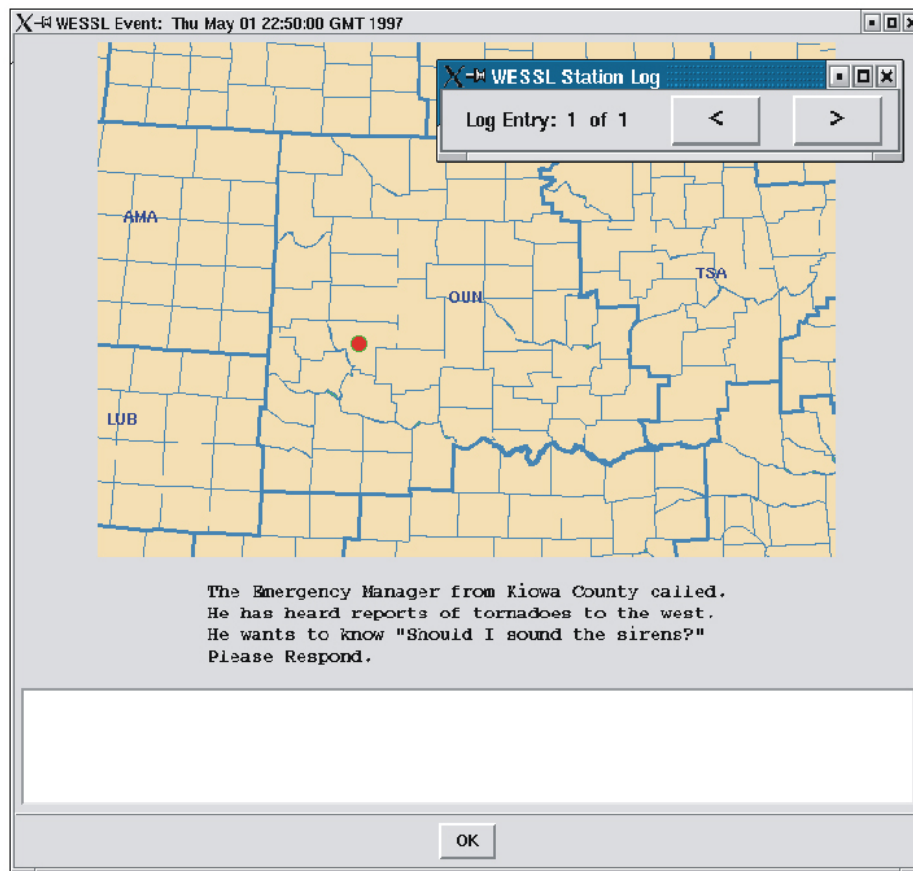
An example of a WESSL event that utilizes a text message, graphic, and query. WESSL allows for the automation of viewable information (like spotter reports, SPC products, etc.) during a simulation. Queries from supervisors or customers also can be used to test participant's situation awareness of possible threats or other issues.

NSSL2: Quantitative Precipitation Estimation and Segregation Using Multiple Sensors –
Flash Flood Tools for FFMP in AWIPS
Howard**, Arthur, Cox**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop GIS basin datasets with hydrologic connectivity attributes to be used in the Flash Flood Monitoring and Prediction System in AWIPS; provide technical support and assistance to NWS Forecast Offices for their FFMP basin dataset customization efforts.

Accomplishments
In 2002, the initial transfer of GIS basin datasets to NWS Weather Forecast Offices (WFOs) for use in the Flash Flood Monitoring and Prediction System was completed. After several Basin Customization training classes at COMET, it was determined that the addition of hydrologic connectivity attributes to the datasets would simplify the task of basin customization while also improving users' understanding of the hydrology in their area. During the past year, 92 basin datasets with hydrologic connectivity attributes were created for use at WFOs. With these additional hydrologic connectivity attributes, the basin datasets can be customized at the WFOs using the AMBER Basin Customization Extension. The extension, which was developed by Paul Jendrowski of the NWS for use within ESRI's ArcView GIS, provides button and menu-driven tools for merging, deleting, and editing basins in a hydrologically-sound manner. In addition, technical support has been provided to numerous WFOs and other FFMP basin dataset users to assist them in understanding and/or customizing their dataset(s). This support ranges from e-mail and phone assistance to helping with the actual customization tasks.
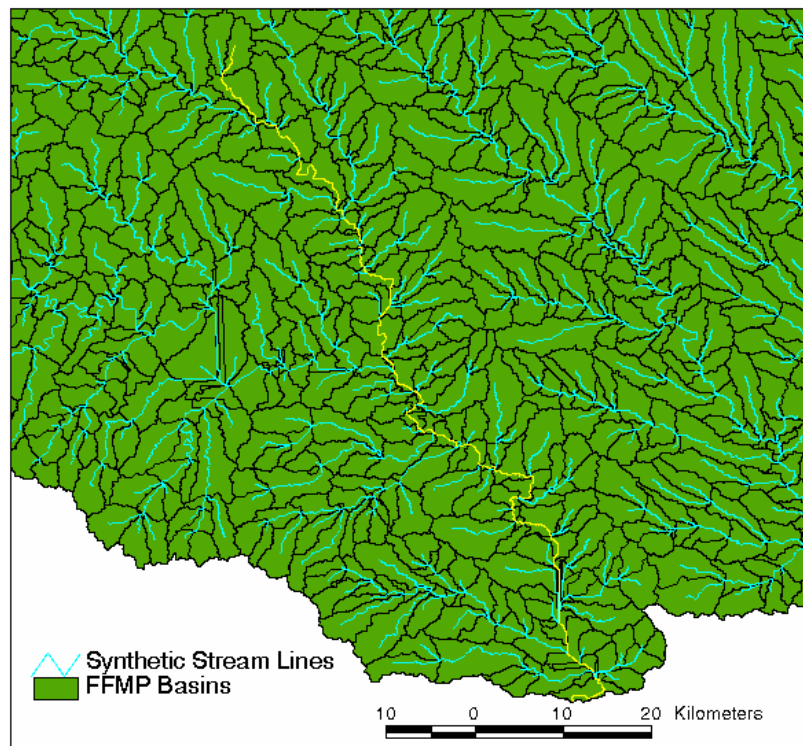
Tracing downstream flow in the FFMP stream and basin datasets. The inclusion of hydrologic connectivity attributes allows the display of upstream/downstream flow characteristics in the FFMP stream and basin datasets using the AMBER Basin Customization Extension within ESRI's ArcView GIS. The visualization of upstream and downstream connectivity between the basins is essential to understanding the hydrology of an area.

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NSSL3: Severe Weather Warning Research and Application Development – *Polarimetric Radar Applications*
Elmore, **Porter**, **Manross**, **Scharfenberg**, **Smith**, **Burgess**, **Farmer**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop, test, and evaluate polarimetric radar outputs for operational meteorology; test and evaluate prototype radar applications at NWS WFO in Norman.

Accomplishments
Data collected with the NSSL's prototype polarimetric WSR-88D (KOUN) during the Joint Polarization Experiment (JPOLE) in 2002-2003 were analyzed. Forecasters from NWS WFO Norman who used the data during their operations were given evaluation forms to fill out and return, and these forms were summarized in a report to the NEXRAD Product Improvement Program. The JPOLE data revealed significant improvement is possible to rainfall accumulation estimation, automated hydrometeor classification, and hail detection. The "Zdr column" signature, an enhanced region of differential reflectivity marking thunderstorm updraft location and strength, was studied using the JPOLE data sets.

During spring 2004, several prototype radar applications were evaluated by forecasters at NWS WFO Norman. These applications included 4D radar data display concepts, multi-radar hail diagnosis tools, and linear least squares derivative (LLSD) shear diagnosis products. Evaluation forms were developed and distributed to forecasters, and CIMMS/NSSL meteorologists were stationed at the WFO during significant events to evaluate the applications and aid forecasters in interpretation. The multiple-radar hail size estimation algorithm and the LLSD "rotation track" product were found to be very helpful to operations and post-storm verification efforts at the WFO.

Publications
Scharfenberg, K. A., 2003: Polarimetric radar signatures in microburst-producing thunderstorms. *Preprints, 31st International Conf. on Radar Meteorology*, Seattle, WA, Amer. Meteor. Soc., 581-584.

Scharfenberg, K. A., D. L. Andra Jr., and M. P. Foster, 2003: Operational uses of polarimetric radar in severe local storm prediction. *Preprints, 31st International Conf. on Radar Meteorology*, Seattle, WA, Amer. Meteor. Soc., 632-634.

Scharfenberg, K. A., and E. Maxwell, 2003: Operational use of a hydrometeor classification algorithm to detect the snow melting level. *Preprints, 31st International Conf. on Radar Meteorology*, Seattle, WA, Amer. Meteor. Soc., 639-641.

Scharfenberg, K. A., D. J. Miller, P. Heinselman, D. L. Andra, Jr., and M. P. Foster, 2004: Highlights from the Joint Polarization Experiment operational demonstration. *Preprints, 20th Conf. on Weather Analysis and Forecasting*, Seattle, WA, Amer. Meteor. Soc., CD-ROM, 10.5.

National Weather Service Weather Forecast Office - Norman, OK Meteorologist in Charge Michael P. Foster demonstrates the NSSL Warning Decision Support System - Integrated Information (WDSS-II) to National Weather Service director Brigadier General (ret.) David L. Johnson. On the screen is data from the NSSL's prototype polarimetric WSR-88D that were collected and transferred to WFO Norman forecasters in real-time as part of JPOLE. CIMMS scientists played large roles in the development of WDSS-II and in conducting JPOLE.

NSSL4: Investigation into the Use of Warning Decision Support Systems for Improving Hazardous Weather Detection, Warnings, and Forecasts – *Multiple-Sensor Severe Application Development using WDSS-Integrated Information*
Stumpf, Smith, Manross, Lakshmanan, Scharfenberg, Elmore, Song, Toomey, Cooper, Hondl**, Brogden, Kerr, Hocker, Ortega, Adams**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Improve the accuracy and timeliness of severe weather warning applications for the NWS and other users by integrating multiple-radar and multiple-sensor data.

Accomplishments
CIMMS has played the primary role in the prototype development and evaluation of severe weather warning applications used to analyze storm information using data from multiple Doppler radars and other remote sensing instruments (e.g. satellites, lightning detection networks, mesoscale models). Integrating data from multiple data sources reduces the uncertainty of the measurements, increases the accuracy of

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the diagnoses of severe weather, and allows forecasters to make more effective warning decisions. During the previous year, CIMMS scientists continued to make improvements to these applications and develop new techniques for processing these voluminous data streams.

A variety of new multiple-radar and multiple-sensor severe weather warning applications were improved or developed during this year. The research and development process was greatly facilitated by use of the Warning Decision Support System - Integrated Information (WDSS-II) infrastructure. A Near-Storm Environment algorithm that ingests model data and generates over one hundred fields based on model analysis data has enabled greater use of the background environment fields in several different applications. These data are being tested in a polarimetric hail-detection algorithm and a multi-radar precipitation estimation algorithm that were both developed in the last year, and have also been added as improvements to existing applications that estimate storm motion, quality control reflectivity data, and other storm analysis applications. Improvements were also made to the multi-radar shear diagnosis routines for tracking mesocyclones and other circulations (see figure below). We are also working toward improved multiple-sensor radar echo segregation, reflectivity motion estimates, and lightning prediction. Many of the new severe weather warning applications were tested in real-time NWS operations at Norman, OK, and Wichita, KS.

Publications

Lakshmanan, V., K. Hondl, G. Stumpf, and T. Smith, 2003: Quality control of WSR-88D data. *Preprints, 31st Radar Conference*, Amer. Meteor. Soc., Seattle, WA, 522-525.

Lakshmanan, V., K. Hondl, G. Stumpf, and T. Smith, 2003: Quality control of weather radar data using texture features and a neural network. *13th Intl Conf on Pattern Recognition*, Kolkota, India.

Smith, T. M., K. L. Elmore, and S. A. Dulin, 2004: A damaging downburst prediction and detection algorithm for the WSR-88D. *Wea. Forecasting*. **19,** 240-250, Amer. Met. Soc.

Smith, T. M., K. E. Elmore, G. J Stumpf, and V. Lakshmanan, 2003: Detection of rotation and boundaries using two-dimensional, local, linear least squares estimates of velocity derivatives. *Preprints, 31st Conf. on Radar Meteor*. Seattle, WA, Amer. Met. Soc.

Stumpf, G. J., T. M. Smith, K. L. Manross, V. Lakshmanan, and K. D. Hondl, 2003: Severe weather warning application development at NSSL using multiple radars and multiple sensors. *Preprints, 31st Conf. on Radar Meteor*., Seattle, WA, Amer. Meteor. Soc., 555-558.

Stumpf, G. J., T. M. Smith, and C. Thomas, 2003: The National Severe Storms Laboratory's contribution to severe weather warning improvement: multi-sensor severe weather applications. *Atmos. Res.*, **67-68**, 657-669, Elsevier B.V.

Stumpf, G. J., T. M. Smith, V. Lakshmanan, K. L. Manross, and K. D. Hondl, 2004: Status of multiple-sensor severe weather application development at NSSL. *Preprints, 20th Intl. Conf. on Interactive Information and Processing Systems (IIPS) for Meteor., Oceanography, and Hydrology*, Seattle, WA, Amer. Meteor. Soc., 12.3a - CD preprints.

Stumpf, G. J., W. D. Zittel, A. Witt, T. M. Smith, V. K. McCoy, and S. Dulin, 2004: Using a reflectivity "scale filter" to improve performance of the Storm Cell Identification and Tracking (SCIT) algorithm. *Preprints, 20th Intl. Conf. on Interactive Information and Processing Systems (IIPS) for Meteor., Oceanography, and Hydrology*, Seattle, WA, Amer. Meteor. Soc., P1.3 - CD preprints.
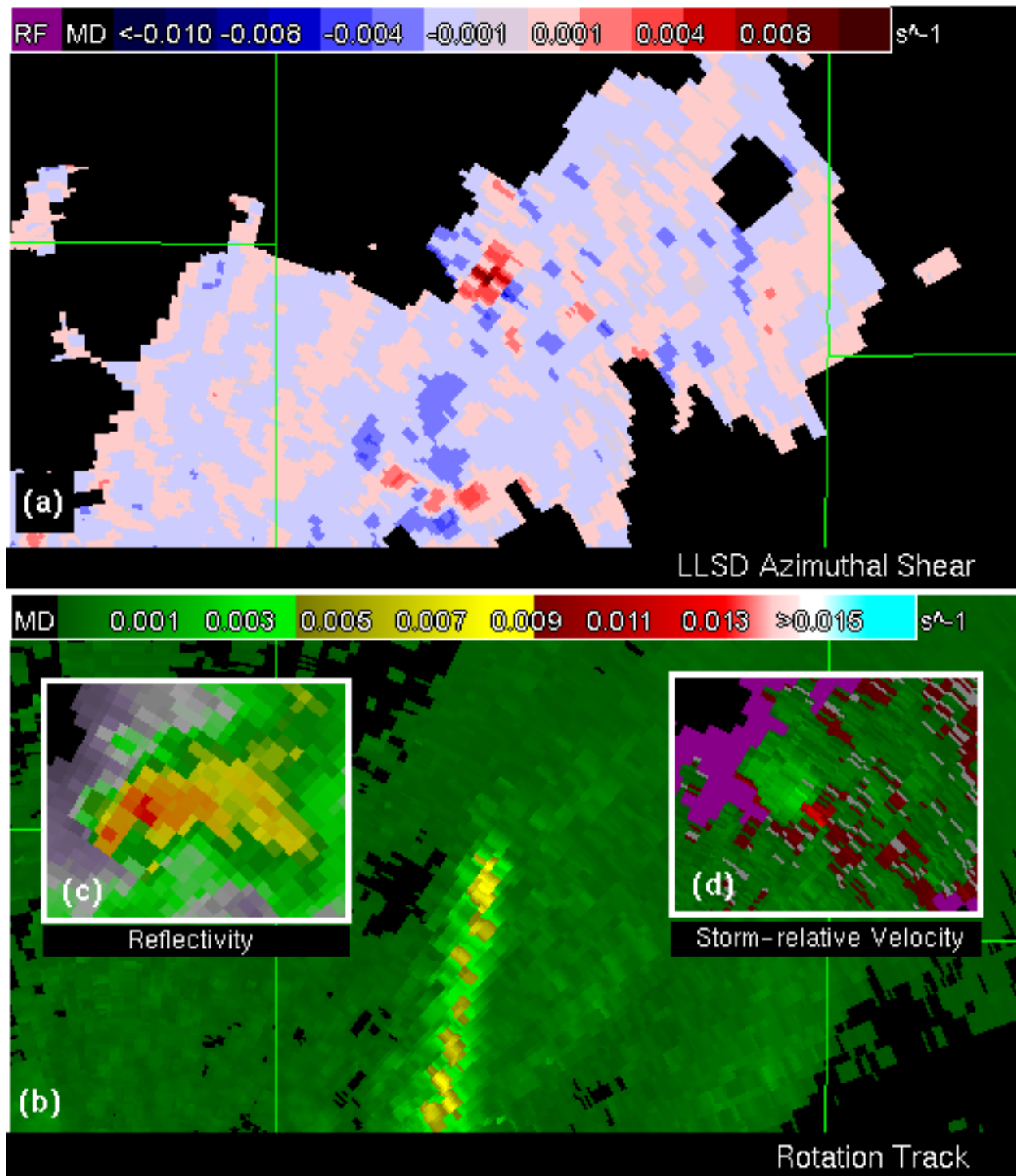
Example of advances in warning decision-making tools using WDSS-II. Insets (c) and (d) show conventional displays of reflectivity and velocity data available from Doppler weather radar. The image in (a) is a depiction of shear within the storm that is computed from the velocity data shown in (d). The red spots indicate locations with high shear. A slow northward movement of the high-shear areas with time is depicted as "rotation tracks" in (b). The graphic in (b) summarizes hours of velocity data into information a human decision maker can immediately use.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *SPC/NSSL Spring Program*
Kain, Baldwin, Weiss, **J. Levit**, Bright

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Design and execute an annual collaborative program that allows forecasters to evaluate new tools or concepts that emanate from the research community, while immersing research scientists in the challenges, needs, and constraints of the operational forecasting environment.

Accomplishments
The 2004 Spring Program was conducted from 19 April through 3 June. The primary scientific goals of this year's program were to 1) assess whether SPC forecasters can make better predictions of severe convective weather when their current datastream of observational and model data is supplemented with output from near-cloud-resolving forecast models, 2) identify specific characteristics of the high resolution output that provide added value, as well as those that might have a detrimental or misleading impact, and 3) compare the performance of the different Weather Research and Forecasting (WRF) model configurations to provide feedback to model developers. Results from the program are currently being summarized and will be shared with all participants.

The Spring Program addresses different operationally relevant scientific issues every year, but the spirit of the program changes very little from year to year. It is driven by a recognition that numerous benefits, many of them intangible and hard to quantify, result when research meteorologists and operational forecasters are brought together to investigate problems of mutual interest. The underlying design promotes forecast improvements in the short term by accelerating the transfer of science and technology into forecast operations at the SPC and in the long term by providing researchers with the knowledge to formulate research strategies that will directly benefit operational forecasting. It also provides academic researchers with hands-on experience and practical information that often finds its way into formal coursework. For example, several academic participants in this year's program indicated that their Spring Program experience would have a significant impact on the specific content of the course that they teach.

This year's program had over 50 participants, including contributors from numerous NOAA research and forecasting organizations, a dozen major universities, the Air Force Weather Agency, NCAR, and international visitors from Canada and Finland.

Publications
Bright, D. R., S. J. Weiss, J. J. Levit, M. S. Wandishin, J. S. Kain, and D. J. Stensrud, 2004: Evaluation of short-range ensemble forecasts during the 2003 SPC/NSSL Spring Program. *Preprints, 22nd Conference on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., CD-ROM, paper P15.5

Kain, J. S., M. E. Baldwin, and S. J. Weiss, P. R. Janish, M. P. Kay, and G. Carbin, 2003: Subjective verification of numerical models as a component of a broader interaction between research and operations. *Wea. Forecasting*, **18**, 847-860.

Kain, J. S., P. R. Janish, S. J. Weiss, M. E. Baldwin, R. S. Schneider, and H. E. Brooks, 2003: Collaboration between forecasters and research scientists at the NSSL and SPC: The Spring Program. *Bull. Amer. Meteor. Soc.*, **84**, 1797-1806.

Kain, J. S., S. J. Weiss, D. R. Bright, M. E. Baldwin, and J. J. Levit, 2004: Subjective verification of deterministic models during the 2003 SPC/NSSL Spring Program. *Preprints, 20th Conference on Weather Analysis and Forecasting/16th Conference on Numerical Weather Prediction*, Seattle, WA, Amer. Meteor. Soc., CD-ROM, 9.3

Dr. John Brown of the NOAA Forecast Systems Laboratory discusses WRF model forecasts at a daily map discussion during the 2004 SPC/NSSL Spring Program.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Evaluating the Weather Research and Forecasting (WRF) Model at the SPC*
Kain, Baldwin, Weiss, **J. Levit**, Bright

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Increase forecaster awareness and understanding of the WRF model, systematically evaluate model utility as an operational tool for forecasting severe convective weather, and provide feedback to WRF developers based on model evaluation at the SPC.

Accomplishments
Over the past year CIMMS scientists have made a unique and influential contribution in the development of the WRF model, playing an active role in model testing and evaluation, and acting as liaisons between the modeling and forecasting communities. In the fall of 2003, they gave a series of 1-2 hour presentations on the WRF model during semi-annual SPC forecaster training. These training sessions focused on the current state of WRF model development and capabilities as well as NWS implementation plans. They provided important background information for SPC forecasters as they prepared to conduct systematic evaluation of the WRF model during the 2004 SPC/NSSL Spring Program.

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The past Spring Program represented the culmination of several years of work with the WRF model. CIMMS scientists have forged partnerships with key WRF model developers at NCAR (National Center for Atmospheric Research), NCEP (National Centers for Environmental Prediction), and OU/CAPS (University of Oklahoma/Center for Analysis and Prediction of Storms) and they collaborated with these partners to generate and evaluate high resolution WRF forecasts during the program. Different high-resolution configurations of these models were used as guidance in preparation of experimental severe weather forecasts and the model output was systematically evaluated by SPC forecasters, NSSL and CIMMS research scientists, and a variety of forecasters and researchers from numerous other government agencies and academic institutions. Results from this study were presented at the joint MM5/WRF workshop in Boulder, CO. As a follow-up on this work, Spring Program organizers are currently consulting with scientists from both NCEP and NCAR to refine operational implementation plans for the WRF model.

Publications

Kain, J. S., S. J. Weiss, J. J. Levit, M. E. Baldwin, and D. R. Bright, 2004: Evaluating the utility of WRF as a severe weather forecasting tool. *Preprints, 5th WRF/14th MM5 User's Workshop*, 22-25 June, Boulder, CO, 184-187.

Weiss, S. J., J. S. Kain, J. J. Levit, M. E. Baldwin, and D. R. Bright, 2004: Examination of several different versions of the WRF model for the prediction of severe convective weather: The SPC/NSSL Spring Program 2004. *Preprints, 22nd Conference on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., CD-ROM, paper 17.1
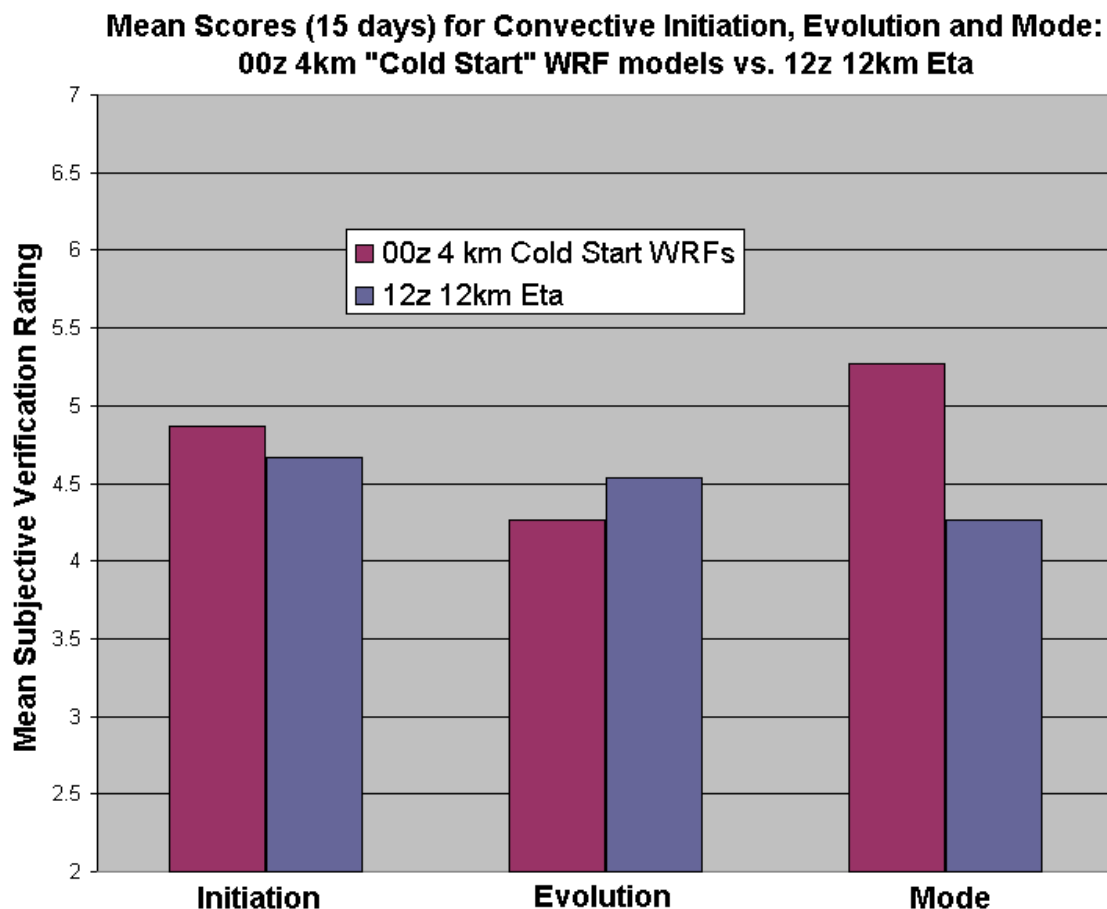
Mean subjective ratings (on a scale of 1-10) for model forecasts from high-resolution WRF models and the operational Eta model, as determined by a panel of expert forecasters and research scientists during the 2004 Spring Program. Different ratings were assigned for convective initiation, evolution, and mode. Differences in the initiation and mode categories are not statistically significant, but convective mode forecasts from the WRF models were significantly better than the operational Eta.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Forecast Verification*
Baldwin, **Kain**, **Elmore**, **Schultz**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop new and unique verification strategies; maintain and continue to build a database of forecasts and observations for ongoing verification studies.

Accomplishments
Automated Data Collection Procedures.   Automated data collection procedures have continued for quantitative precipitation forecasts from NCEP's operational models, an experimental version of the Eta model running twice-daily at NSSL, and experimental versions of the WRF model running at CAPS, NCEP, NSSL and NCAR. These data are available for verification studies using analyses of both raingage observations and the so-called "Stage IV" high-resolution multi-sensor precipitation fields from NCEP, which have also been archived.

Verification Techniques.   Development of new verification techniques has also continued at NSSL. In order to obtain more meaningful verification information, an event- or object-oriented approach to verification continues to be developed. The object-oriented verification approach compares characteristics of meteorological phenomena (objects) that can be identified in forecast and observed spatial fields. As an initial step in this development process, automated procedures for identifying, analyzing, and classifying rainfall systems have been established. The automated classification procedure uses attributes related to rainfall intensity and spatial organization to place rainfall systems into linear, cellular, or stratiform classes. To test the performance of the automated classification procedure, results from 2002 were validated against an expert classification. From an independent random sample, the automated classification procedure accurately classified events into stratiform, linear, and cellular classes 85 percent of the time.

Archive of Forecast Fields.   A long-term archive of several forecast fields, such as winds and temperatures on mandatory pressure levels, from daily runs of NCEP's operational Eta model and NSSL's experimental version of the Eta model has continued. These data are verified against operational Eta analyses and forecast error fields for 24-h forecasts over a 14-month period have been studied in detail. By applying basic statistical tools, appropriate corrections are made for temporal and spatial degrees of freedom, yielding the spatial distribution of 95 percent confidence intervals about the mean error at each grid point. These 2-D plots of mean error can be used by forecasters to improve the model guidance that they use in the preparation of their forecasts. The 500-hPa height errors for mobile shortwave troughs are usually localized and positive (under forecast); errors are believed to mostly be associated with initial-condition errors. On the other hand, the 500-hPa height errors for longwave ridges usually cover a much larger area comparable to the size of the ridge and are also negative (under forecast); errors are believed to mostly be associated with errors in the model, likely the radiation scheme.

Fourier Kinetic Spectra of Forecasts.   In order to determine whether the spatial structure and variability of forecast fields is being predicted in a manner consistent with observations, Fourier kinetic energy spectra of forecasts from various mesoscale models (NCEP NMM, NSSL Eta, NCAR WRF, etc) were analyzed. These results (see figure below) showed that the spectra from the NSSL Eta and NCAR WRF matched the observed spectral slope up to around the 5-7 delta-x scale, where the explicit and implicit energy dissipation mechanisms in the models become dominant. However, the energy dissipation in the NCEP NMM, likely due to explicit horizontal diffusion and divergence damping, began to dominate the results at much larger scales (approximately 20 delta-x). These results are useful to developers of numerical weather prediction models in determining what aspects of the model physics or dynamics are affecting the energy spectra.

Publications

Baldwin, M. E., S. Lakshmivarahan, and J. S. Kain, 2004: Development of an automated classification procedure for rainfall systems. *Mon. Wea. Rev.*, accepted

Baldwin, M. E. and S. Lakshmivarahan, 2003: Spatial characterization of rainfall patterns for use in a classification system. *Intelligent Engineering Systems Through Artificial Neural Networks*, Volume 13, C.H. Dagli, A.L. Buczak, J.Ghosh, M.J. Embrechts, O. Ersoy, Eds., ASME Press, 683-688.

Baldwin, M. E., and J. S. Kain, 2004: Examining the sensitivity of various performance measures. *Preprints, 19th Conf. Probability and Statistics*, Seattle, WA, Amer. Meteor. Soc., CD-ROM, paper 2.9.

Elmore, K. L., D. M Schultz, and M. E. Baldwin, 2004: Field significance revisited: Spatial bias errors in forecasts as applied to the Eta Model. *Mon. Wea. Rev*., accepted.

Skamarock, W. C., M. E. Baldwin, and W. Wang, 2004: Evaluating high-resolution NWP models using kinetic energy spectra. *Preprints, First Joint WRF/MM5 User's Workshop*, NCAR, Boulder, CO, paper 2.2.
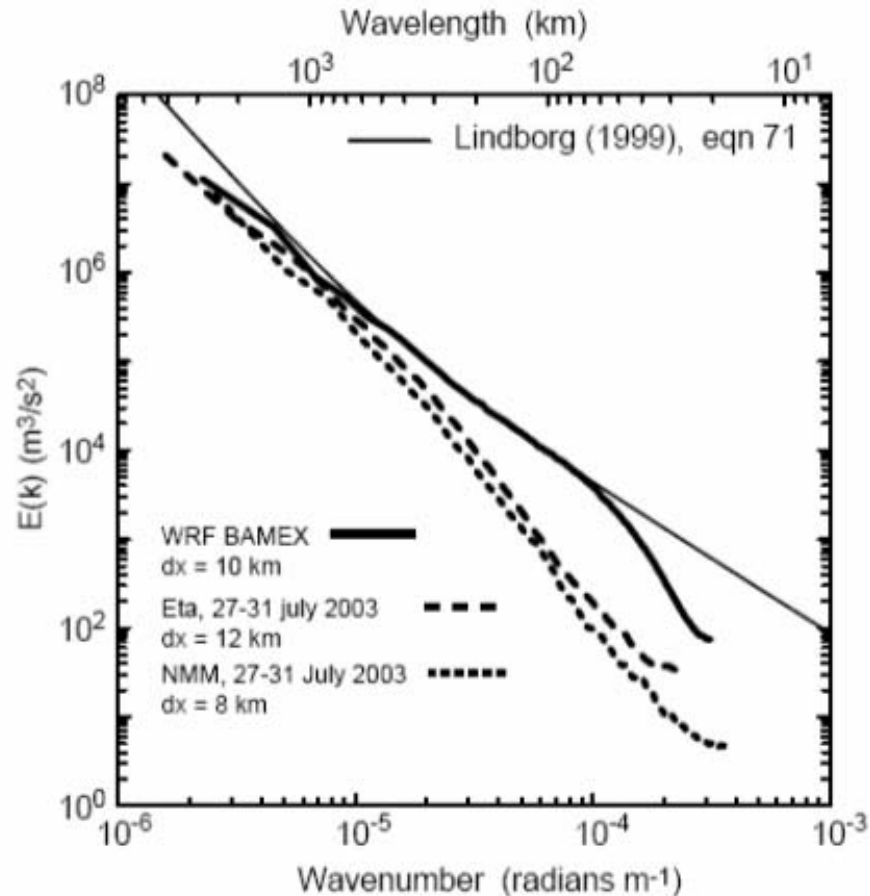
Fourier kinetic energy spectra from operational 12km Eta, 8km NMM, and 10km WRF-BAMEX runs. (Fig. 7 from Skamarock et al. 2004)

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *New England High-Resolution Temperature Project*
Stensrud, **Yussouf**, **Baldwin**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Improve forecasts of temperature, dewpoint temperature, and winds over the New England region using a multimodel short-range ensemble forecasting system in comparison to present operational guidance

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provided by Model Output Statistics (MOS); evaluate the value of multimodel ensembles for short-range forecasting.

Accomplishments

A multimodel short-range ensemble forecasting system created as part of a NOAA pilot program on improved high temperature forecasting during the summer of 2003 has been evaluated. Results from this short-range ensemble system indicate that using the past complete 12 days of forecasts to bias correct today's forecast yields ensemble mean forecasts of 2-m temperature, 2-m dewpoint temperature, and 10-m wind speed that are competitive with or better than those available from any of the three model output statistics presently generated operationally in the United States. However, the bias-corrected ensemble system provides more than just the ensemble mean forecast. The probabilities produced by this system are skillful and reliable, and previously have been found to be valuable when evaluated in a cost-loss model. The ensembles further appear to provide better guidance for more unlikely events, such as very warm temperatures, that likely have the greatest economic significance. Industries that are sensitive to the weather, such as power companies, transportation, and agriculture, may benefit from the probability information provided. Thus, it is possible to develop a post-processing system for new forecast models, when used within a reasonable short-range ensemble forecasting system, that is competitive with or better than traditional post-processing techniques, thereby allowing for the rapid production of useful and accurate guidance forecasts of many near surface variables once an ensemble system is started operationally.

Using the ensemble model data from July and August of 2002, an ensemble of 48-h forecasts has been evaluated using a clustering method over many cases. The ensemble forecasting system consists of 23 total forecasts from four different models: the National Centers for Environmental Prediction (NCEP) Eta Model (ETA), the NCEP regional spectral model (RSM), the rapid update cycle model (RUC), and the Fifth Generation Pennsylvania State University National Center for Atmospheric Research mesoscale model (MM5). Forecasts of 2-m temperature, 850-hPa u-component wind speed, 500-hPa temperature, and 250-hPa u-component wind speed are bilinearly interpolated to a common grid and a cluster analysis is conducted at each of the 17 output times for each of the case days using a hierarchical clustering approach. Results from the clustering indicate that the forecasts largely cluster by model, with these intra-model clusters occurring quite often near the surface and less often at higher levels in the atmosphere. Results also indicate that model physics diversity plays a relatively larger role than initial condition diversity in producing distinct groupings of the forecasts. If the goal of ensemble forecasting is to have each model forecast represent an equally likely solution, then this goal remains distant as the model forecasts too often cluster based upon the model that produces the forecasts. Ensembles that contain both initial condition and model dynamics and physics uncertainty are recommended.

Multimodel ensemble data from the summer of 2004 are being collected and the bias-correction approach compared against Model Output Statistics (MOS). Exploration of other approaches to improving the forecasts also is underway. In addition, methods to improve upon precipitation forecasts will be investigated.

Publications

Stensrud, D.J., and N. Yussouf, 2003: Short-range ensemble predictions of 2-m temperature and dewpoint temperature over New England. *Mon. Wea. Rev.*, **131**, 2510-2524.

Yussouf, N., D.J. Stensrud, and S. Lakshmivarahan, 2004: Cluster analysis of multimodel ensemble data over New England. *Mon. Wea. Rev.*, in press.

Stensrud, D.J., and N. Yussouf, 2004: Bias-corrected short-range ensemble forecasts of near surface variables. *Meteor. Appl.*, submitted.
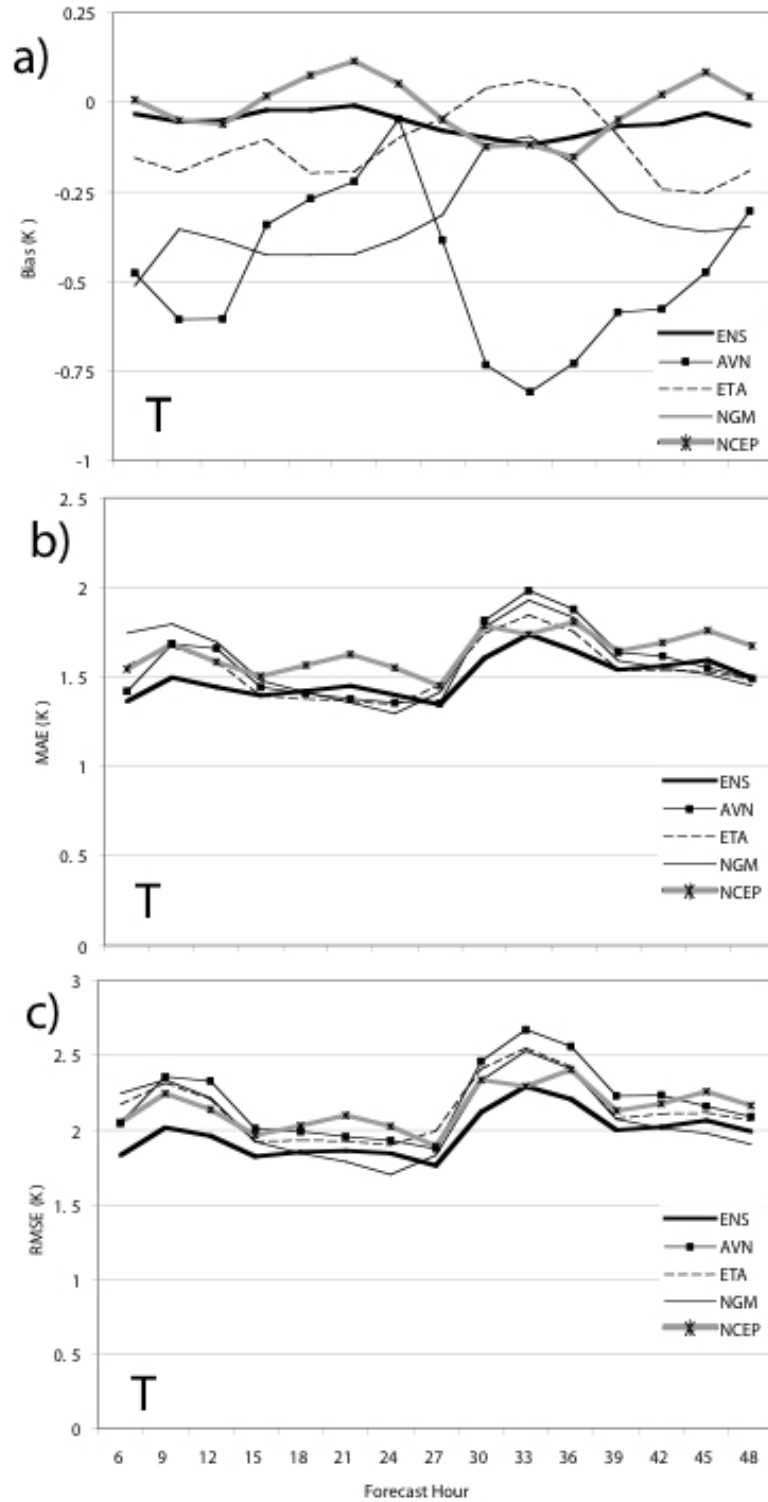
Values of (a) mean bias (K), (b) mean absolute error (K), and (c) root-mean-square error (K) plotted as a function of forecast hour for 2-m temperature from the full 31 member BCE, the NCEP-only BCE, and the AVN, ETA, and NGM MOS. Results are calculated at 1,258 station locations for the ensemble and AVN and ETA MOS data, and at only 565 station locations for the NGM MOS. Further details are found in the legend.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Intraseasonal Variability of the North American Monsoon over Arizona*
Heinselman, **Schultz**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Investigate the intraseasonal variability of diurnal storm development over Arizona and the importance of synoptic-scale forcing during the North American Monsoon.

Accomplishments
Radar reflectivity mosaics constructed from Phoenix and Flagstaff WSR-88D reflectivity data reveal five repeated storm development patterns or regimes. The diurnal evolution of each regime is illustrated by computing frequency maps of reflectivity 25 dBZ and greater during 3-h periods (see figure below). The first regime is indicated by a lack of rainfall over the domain (dry regime, DR). The second is characterized by storm development over mountainous terrain in eastern Arizona only (eastern mountain regime, EMR), whereas the third is characterized by storm development over both mountainous terrain in eastern Arizona and the Mogollon Rim (central/eastern mountain regime, CEMR). The fourth regime is similar to the summertime diurnal climatology, where storms develop initially over both the Mogollon Rim and mountains of eastern Arizona, and later move toward lower elevations, culminating in the Sonoran Desert (central/eastern mountain and Sonoran regime, CEMSR). The final regime is characterized by organized storm development that is tied less strongly to the diurnal cycle (non-diurnal regime, NDR). The tendency for repeated storm development over different geographic regions indicates that storm growth is tied strongly to terrain forcing and the synoptic-scale environment.

Composites of 1200 UTC 500-hPa geopotential heights over the southwest United States constructed from the NCEP/NCAR Reanalysis Project data show that regime occurrence is related to the N-S location of the horizontal ridge axis of the Bermuda High and the E-W location of the monsoon boundary, which, in turn, controls the moisture field. Indeed, 1200 UTC composite Phoenix soundings reveal that values of precipitable water (surface 400 hPa) are lowest during DR, when the horizontal ridge axis is located over southern Arizona at 30°N. During the other four regimes, values of precipitable water at Phoenix depend on the location of the monsoon boundary: east of Phoenix during EMR and west of Phoenix during CEMR, CEMSR, and NDR. Further analysis of daily 1200 UTC Phoenix sounding variables shows that precipitable water and surface 6-km shear distinguish among the five regimes best. Surface 6-km shear is most important for discerning the potential for CEMR, CEMSR, or NDR, owing to the stronger flow and synoptic-scale forcing associated with NDR.

Publications

Heinselman, P. L., 2004: Intraseasonal variability of the North American Monsoon over Arizona. Ph.D. dissertation, University of Oklahoma, Norman, OK, 138 pp.
Heinselman, P. L., and D. M. Schultz, 2004: Intraseasonal variability of summer storms over Arizona. *Wea. Forecasting.*, submitted.
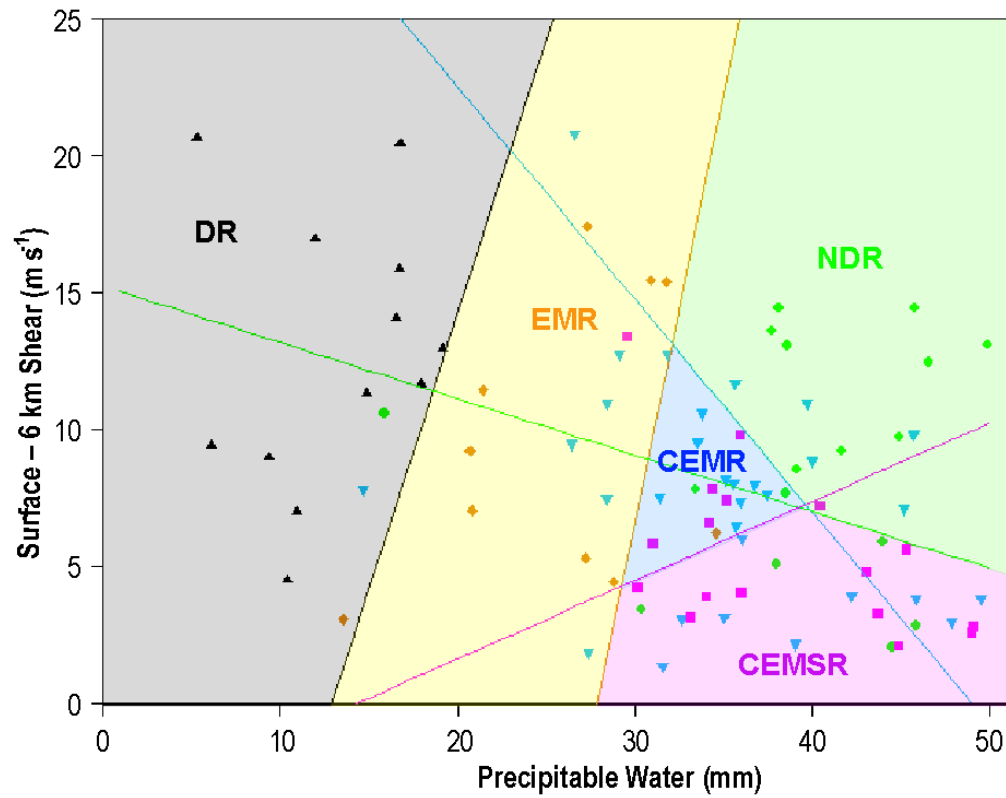
Figure 1. Combined discriminant analyses of PW and SHR. Colored lines represent

the dividing line between regimes, where discriminant analyses include: black: DR. vs all other

regimes, orange: EMR vs CEMR, green: CEMSR vs NDR, blue: CEMR vs NDR, and pink: CEMR

vs CEMSR. Each regime is denoted by a symbol, where DR is a black triangle, EMR is an orange

diamond, CEMR is a blue upside-down triangle, CEMSR is a pink square, and NDR is a light

green circle. Colored shading indicates regions where each regime is best classified by this

combined analysis.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Refinement and Continued Development of the Kain-Fritsch Convective Parameterization*
Kain, Baldwin

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Refine and further develop the Kain-Fritsch convective parameterization and to consult with worldwide users of the scheme.

Accomplishments
Refinement of the Kain-Fritsch convective parameterization continued this year, as did consultation with external users. Refinements included the introduction of tracer calculations (essential for air quality work) and shallow convection, along with changes to the updraft and downdraft sub-models, based on feedback from the SPC and evaluation of real time numerical testing in the Eta model. Consultation with other users in the past year has involved approximately ten different institutions in the U.S. and another ten internationally. The scheme is currently being used for operational numerical weather prediction in the U.S., Canada, and Japan.

Publications
Chen, S.-H., T. Kindap, J. Dudhia, and J. S. Kain, 2004: A qualitative study of PM10 transport using a MM5 tracer model. *Geophys. Res. Let.*, submitted.
Kain, J. S., 2004: The Kain-Fritsch convective parameterization: An update. *J. Appl. Meteor.*, **43**, 170-181.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Effects of Land Use Changes on Numerical Models*
R. McPherson, **Stensrud**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Determine how changes in land use can influence a forecast from a mesoscale numerical model.

Accomplishments
Evidence exists that a large-scale alteration of land use by humans can cause changes in the climatology of the region. The largest-scale transformation is the substitution of native landscape by agricultural cropland. This modeling study examines the impact of a direct substitution of one type of grassland for another – in this case, the replacement of tallgrass prairie with winter wheat. The primary difference between these grasses is their growing season: native prairie grasses of the U.S. Great Plains are warm-season grasses whereas winter wheat is a cool-season grass.

Case-study simulations were conducted for 27 March 2000, 5 April 2000, and 14 July 2000 – days analyzed in previous observational studies. The simulations provided additional insight into the physical processes involved and changes that occurred throughout the depth of the planetary boundary layer. Results indicate the following: (1) with the proper adjustment of vegetation parameters, land use type, fractional vegetation coverage, and soil moisture, the numerical simulations were able to capture the overall patterns measured near the surface across a growing wheat belt during benign springtime conditions in Oklahoma; (2) the impacts of the mesoscale belt of growing wheat included increased values of latent heat flux and decreased values of sensible heat flux over the wheat, increased values of atmospheric moisture near the surface above and downstream of the wheat, and a shallower planetary boundary layer (PBL) above and downstream of the wheat; (3) in the sheared environments that were examined, a shallower PBL that resulted from growing wheat (rather than natural vegetation) led to reduced entrainment of higher momentum air into the PBL and, thus, weaker winds within the PBL over and downwind from the growing wheat; (4) for the cases studied, gradients in sensible heat were

insufficient to establish an unambiguous vegetation breeze or its corresponding mesoscale circulation; (5) the initialization of soil moisture within the root zone aided latent heat fluxes from growing vegetation, while the soil moisture near the surface altered sensible heat fluxes from bare soil or sparse vegetation; and (6) reasonable specification of land surface parameters was required for the correct simulation and prediction of surface heat fluxes and resulting boundary-layer development.

Publications

McPherson, R. A., and D. J. Stensrud, 2004: Influences of a winter wheat belt on the evolution of the boundary layer. *Mon. Wea. Rev.*, submitted.

McPherson, R. A., D. J. Stensrud, and K. C. Crawford, 2004: The impact of Oklahoma's winter wheat belt on the mesoscale environment. *Mon. Wea. Rev.*, **132**, 405-421.
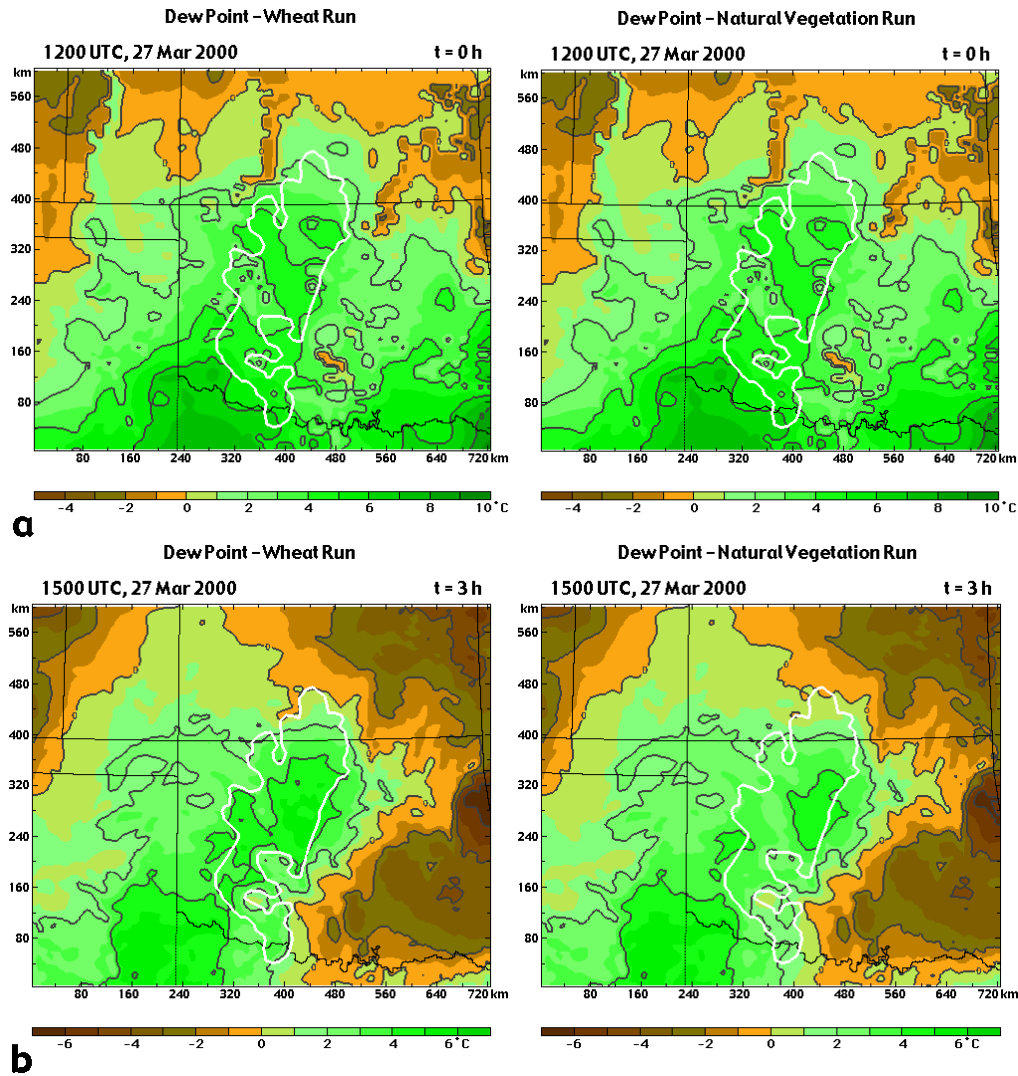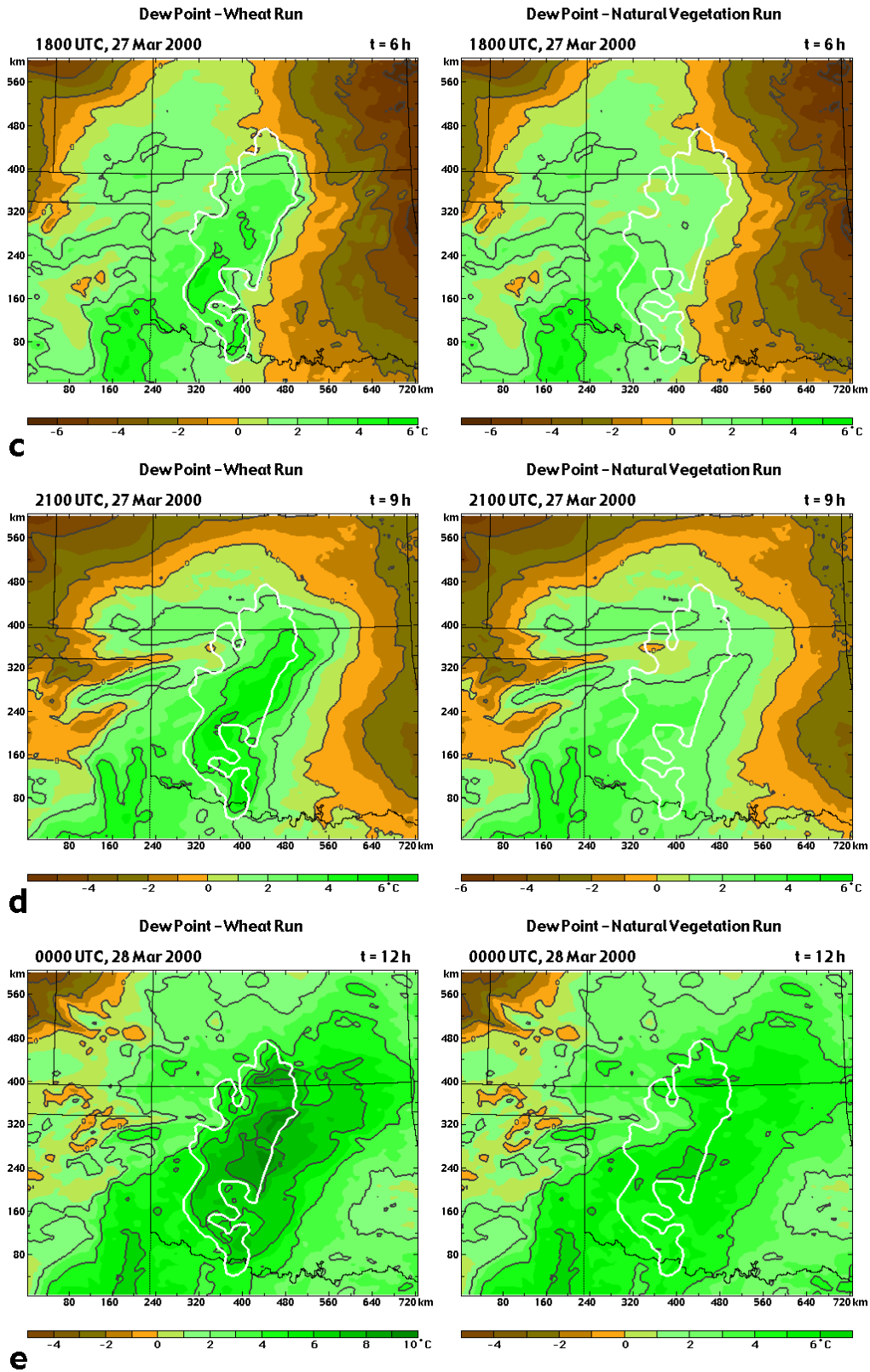
Dewpoint fields at the lowest sigma level for the wheat run (left) and the natural vegetation run (right) for 27 March 2000. The times displayed are (a) 1200 UTC on 27 March, (b) 1500 UTC, (c) 1800 UTC, (d) 2100 UTC, and (e) 0000 UTC on 28 March. The white outline depicts the boundary of the wheat belt.

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NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Objective Analysis Studies*
Spencer, Gao

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Determine if gradient information derived from scalar observations can be used to improve the analysis of the scalar itself.

Accomplishments
A variational scheme for the analysis of scalar variables was developed and compared to 2-pass and 3-pass versions of the Barnes analysis scheme. The variational scheme is similar to a previously-developed variational scheme in that scalar gradient "observations" are used in addition to the scalar observations themselves. The current scheme is different in that the cost function does not require analyses of the scalar field and its gradient; it simply requires scalar and gradient "observations" at their native locations.

Results indicate that the proposed variational scheme is superior to both 2-pass and 3-pass Barnes schemes, increasingly so as the observations become more irregularly spaced. This is true even when the gradient information is not allowed to affect the variational analyses. When the observations are relatively sparse and irregularly distributed, further improvements in the variational analyses occur when the gradient information is properly included within the analysis scheme.

Publications
Spencer, P.L. and J. Gao, 2004: Can gradient information be used to improve variational objective analysis? *Mon. Wea. Rev.*, accepted.

NSSL6: Investigation of Synoptic and Mesoscale Meteorological Processes Associated with Hazardous Weather – *Development of a Mobile Digital Network for Communication of Real-time Meteorological Observations*
Ziegler, Rasmussen, Johns**,** Kennedy

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop a mobile wireless network for communicating real-time mesoscale weather observations in mobile field experiments. A secondary objective was to deploy and test the mobile network during the International H2O Project (IHOP-2002). In addition to forming a critical component to IHOP, this technology could potentially assist short-range severe weather forecasting and other applications requiring wireless mobile digital communications at high bandwidth.

Accomplishments
This research documents the development of a wireless network of instrumented vehicles and aircraft for the real-time collection and synthesis of their mobile weather observations in mesoscale field experiments. The mobile digital network (MDN) utilizes 900 MHz radio frequency modem technology, enabling real-time data transmissions at up to 115 kilobit s^{-1} across a domain of about 40 km on a side. The effective throughput of the network of multiple mobile units is about 40 kilobit s^{-1} due to overhead from data quality checking and acknowledgement that data have been received. After gathering data from mobile observing platforms at a centrally located mobile command post, both image products and data are then uplinked via geostationary satellite at about 80 kilobit s^{-1} and served to the Internet. The first application of the MDN involved mobile field observations obtained during the International H2O Project (IHOP).

Publications

Ziegler, C., D. Kennedy, and E. Rasmussen, 2004: A wireless network for collection and synthesis of mobile mesoscale weather observations. *J. Tech.*, in press.
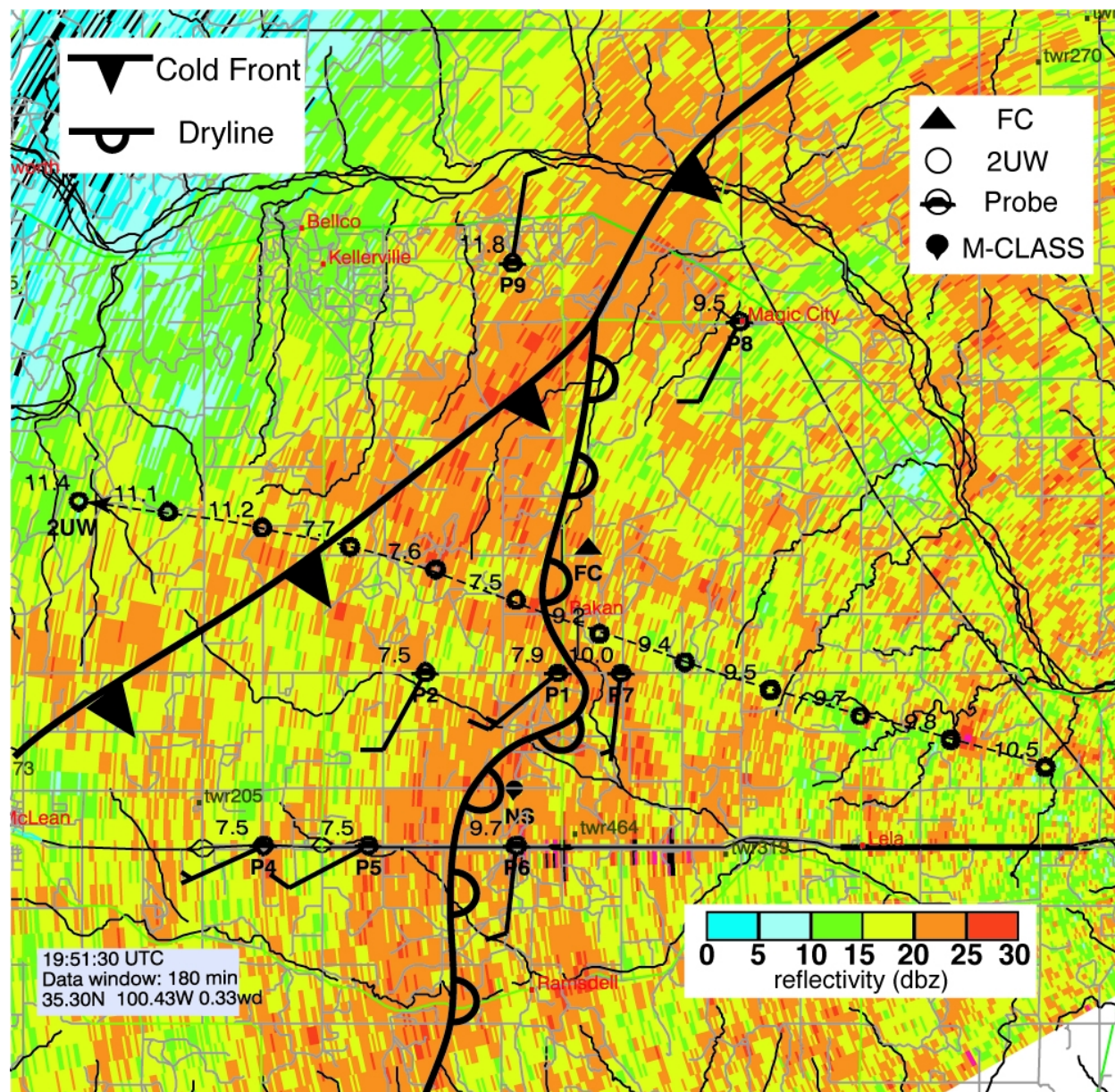
Simulated real-time computer display generated with MDN packets and archived SMART-radar (SR-1) data from 24 May 2002 using the "playback" function of the field coordination (FC) real-time data display program (Ziegler et al 2004). A dryline and cold front were observed in the eastern Texas Panhandle by eight mobile mesonets, the Wyoming King Air, the SMART R-1 radar, and other mobile platforms. The FC vehicle was repositioned toward the northwest of Shamrock, Texas, and began receiving both mobile in-situ data and reflectivity images from the SMART R-1 located east of Shamrock. The field coordinators used this information on the frontal and dryline locations to deploy the mobile mesonets and mobile sounding systems from Shamrock along three east-west roads that transected the boundaries. The rapid southeastward progression of the cold front was easily visualized by the real-time display of radar, surface, and aircraft measurements, enabling the decision to fix the observing domain to best observe the evolving frontal-dryline intersection as it crossed the network. In each of the CI missions conducted during IHOP, the ability to track the surface weather boundaries in the FC vehicle's real-time display helped to optimize the deployment of the mobile facilities and improve the overall data quality.

NSSL9: Research on Integration and Use of Multi-Sensor Information in Weather Forecasting – *Science and Technology Infusion*
Stumpf

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Facilitate CIMMS/NSSL scientists in developing multiple-sensor severe weather and flash flood applications for NWS operational systems; set up an AWIPS Development Environment at CIMMS/NSSL; eventually set up several multi-sensor severe weather testbeds at select NWS forecast offices nationwide.

Accomplishments
A new job position was initiated at CIMMS/NSSL in April 2004 to facilitate scientific and technology infusion for NWS severe weather warning decision making operations. An "AWIPS-Lite" system has been procured, which will foster seamless development of new multiple-sensor applications for severe weather and flash flood warning decision making. Also, new areas of multiple-sensor application development have been initiated. One involves development of more robust hail diagnosis tools using conventional multi-radar data and mesoscale model analysis fields. Another is the continued development of a multi-sensor lightning initiation application.
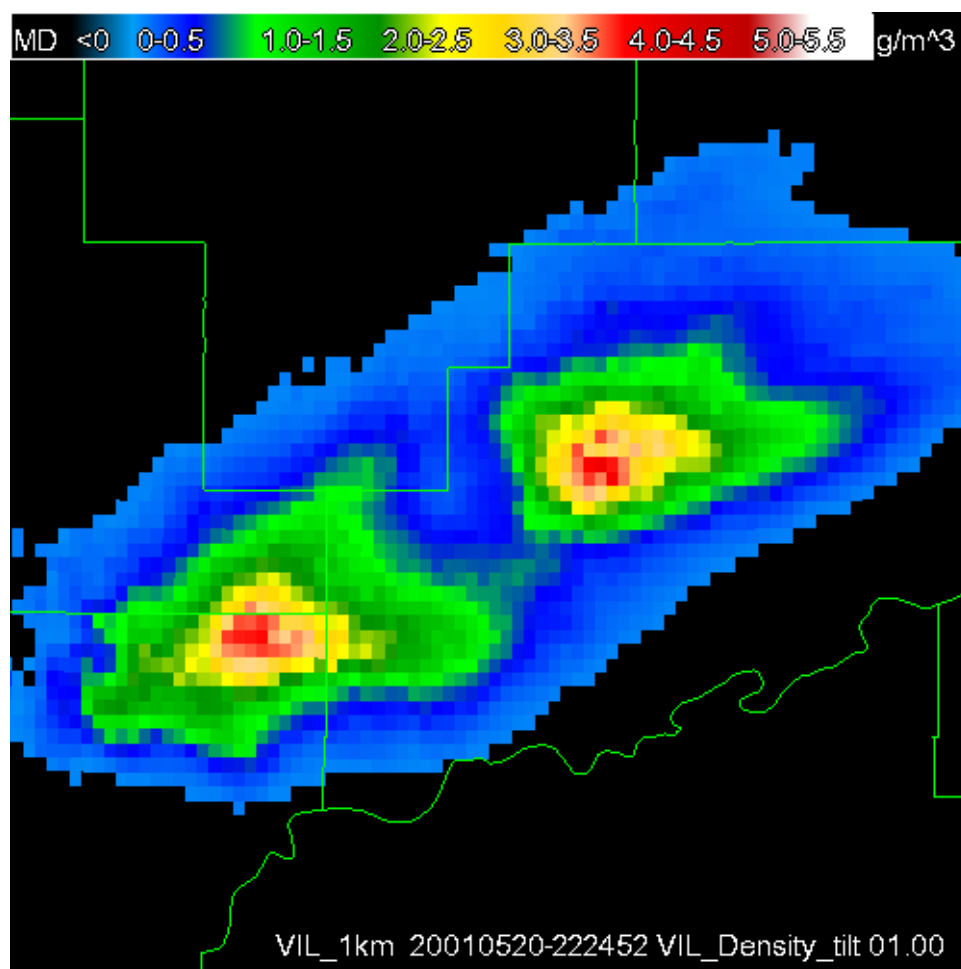
VIL Density (g m³) computed using a tilted vertical integration along the tilt of two supercell storm cores, from 20 May 2001 in eastern Oklahoma.

SPC: Advancing Science to Improve Knowledge of Mesoscale Hazardous Weather
Dean

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Provide research support to the operational forecasting activities at the SPC to improve forecasts of mesoscale hazardous weather.

Accomplishments
The main efforts of this project have been directed towards enhancing the forecast verification system at SPC. There are two main goals for this effort. First, forecast verification at SPC must be modernized to account for the new "Watch-by-County" system of issuing (in collaboration with NWS forecast offices) Severe Thunderstorm and Tornado Watches to the public. The second motivation is to further enhance continuing forecast improvements at the SPC by providing timely and useful forecast verification to forecasters, who can use such information to refine their forecasts as time goes on.

This project involves both software development and scientific aspects. In collaboration with the Science Support Branch (SSB) of the SPC, a database is being developed to collect all forecasts and reports of severe weather pertinent to the SPC, which will allow for a flexible verification scheme that can look both at overall measures of skill, as well as measures of skill in specific forecast scenarios. Such scenarios might involve cases of ongoing severe weather compared to cases where severe weather is anticipated but has not initiated at the time of the forecast. The scientific aspect of this project lies in determining which measures of forecast skill are appropriate for different types of forecasts, as well as determining which subsets of the forecasts and/or observations are appropriate to examine in greater detail in order to provide useful information to the forecasters.

While the new verification system at SPC will likely be undergoing continual refinement for the next several years, functionality that will meet the two main goals of this project should be in place by early 2005.

SRH: An Investigation of Communicating Weather Information Effectively using the Internet
Minton

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Study system response and extraction times associated with different display and extraction methodologies.

Accomplishments
During the project period, CIMMS and DET computer scientists will use readily available weather information to study system response and extraction times associated with different display and extraction methodologies, some of which will be created during this project. Human factors research will also be incorporated into the design of any new methodologies based on an analysis of several experimental user interfaces. Additional research will study various system variables associated with these methodologies, such as amount of CPU and storage usage that occurs, to determine the resources needed to use them. Several current technologies will be incorporated into the study of these new methodologies, including netCDF databases and Geographic Information System (GIS) interfaces.
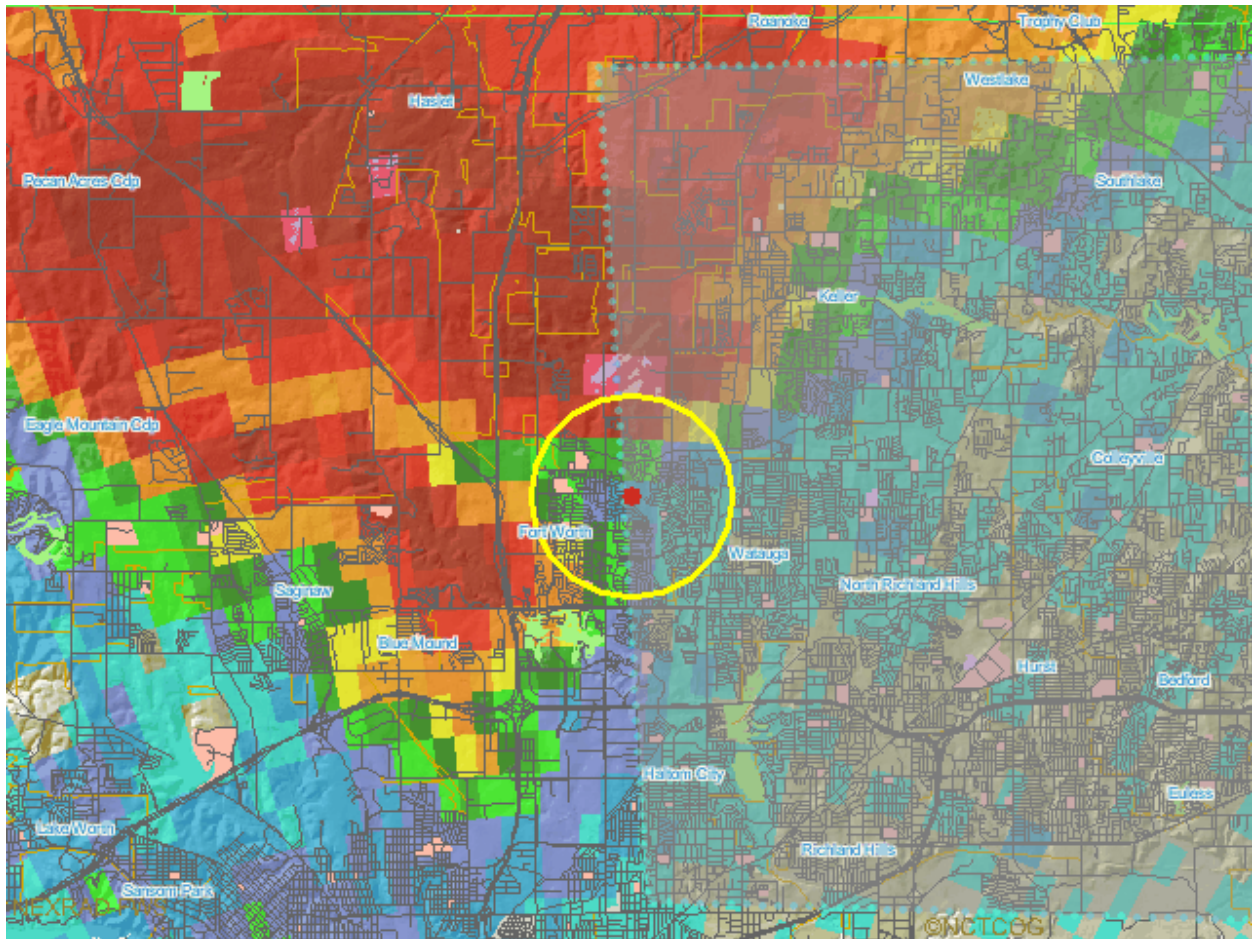
GIS-based radar display, representing a new way to display radar data on the Internet. This work is being done in conjunction with the North Texas Council of Governments and the NWS Forecast Office in Fort Worth.

Cloud-Processing of Aerosol in Regional Forecast Models
Robinson, **Mechem**, **Y. Kogan**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Formulate improvements in how regional models represent cloud-aerosol interactions; characterize cloud processing of aerosol in COAMPS using the CIMMS bulk drizzle scheme.

Accomplishments
Cloud-mediated aerosol indirect effects play an important role in stratocumulus by modulating cloud lifetime. Low cloud condensation nuclei (CCN) loads can lead to precipitation enhancement and the emergence of mesoscale organization as the boundary layer transitions from a well-mixed state into a conditionally stable, decoupled condition. The NRL COAMPS model, equipped with the CIMMS bulk drizzle scheme, represents well the coagulation side of this process. Although aerosol activation and processing are only crudely represented, cloud processing of some fashion takes place as well. Preliminary results from a CCN budget show that fraction of CCN removed by cloud for a moderate CCN load of 200 cm^{-3} can reach 60 percent. Furthermore, CCN processing is strongly correlated with drizzle rate (see figure below) for all aerosol loads. Only unrealistically large in-situ sources are able to maintain steady-state CCN concentrations, though steady-state conditions are possible via entrainment of polluted

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free tropospheric air. The importance of the entrainment source implies that remote sensing of CCN may be as vital as better knowledge of source rates in improving forecasting of strongly coupled aerosol-cloud systems.

Publications

Mechem, D. B., and Y. L. Kogan, 2003: Drizzle-induced mesoscale variability of boundary layer clouds in a regional forecast model. *Preprints, 5th Conference on Coastal Atmospheric and Oceanic Prediction and Processes*, 6-8 August 2003, Seattle, WA, Amer. Meteor. Soc.

Mechem, D. B., and Y. L. Kogan, 2003: Simulating the transition from drizzling marine stratocumulus to boundary layer cumulus with a mesoscale model. *Mon. Wea. Rev.*, **131**, 2342-2360.
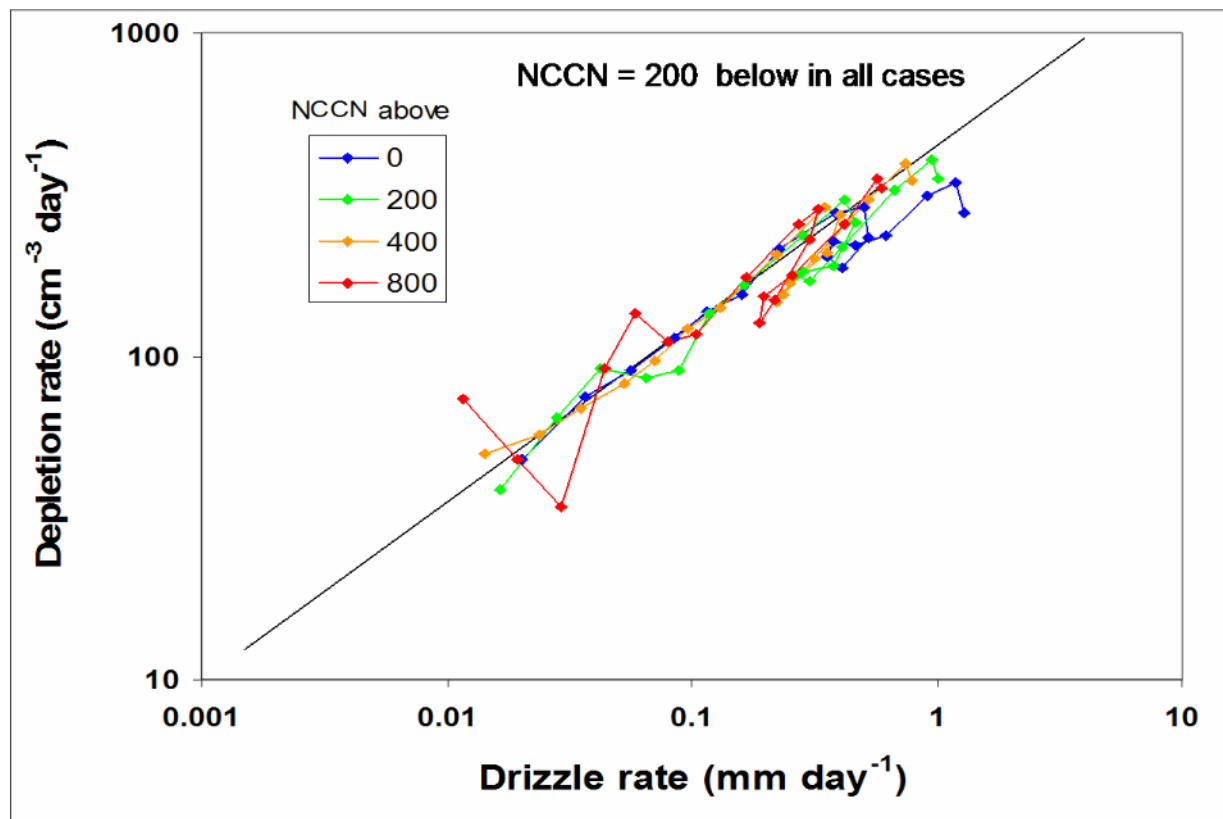
CCN depletion as a function of surface drizzle rate. This figure shows a robust relationship between cloud processing and drizzle for a moderate CCN load. The relationship is robust even when varying entrainment source strengths -- various values of free tropospheric CCN concentrations.

Advanced Weather Data Visualization
J. Levit, Ebert, Riley, Hansen

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop a prototype visually-accurate weather data rendering system, using the latest computer graphics technology.

Accomplishments
Our software system continues to be developed and beta-tested with enhancements added to visualize WRF data with a stretched vertical grid. Previously, the system could only render WRF data with a non-stretched grid. Additionally, some changes have been made to the lightning model that allow for

chromatic effects (rainbows, sunset colors, etc.), and enhancements were made to some of the numerics of the rendering system.

Publications

Riley, K., D. Ebert, M. Kraus, J. Tessendorf, and C. Hansen, 2004: Efficient rendering of atmospheric phenomena. *Proc., Eurographics Symposium on Rendering 2004*, June 2004.

Riley, K., D. Ebert, C. Hansen, and J. Levit, 2003: Visually accurate multi-field weather visualization. *Proc., IEEE Visualization 2003*, pp. 279-286.

Riley, K., D. Ebert, C. Hansen, and J. Levit, 2004: A system for realistic weather rendering. *Preprints, 20th International Conf. on Interactive Information and Processing Systems (IIPS) for Meteor., Oceanography, and Hydrology*, Seattle, WA, Amer. Meteor. Soc.
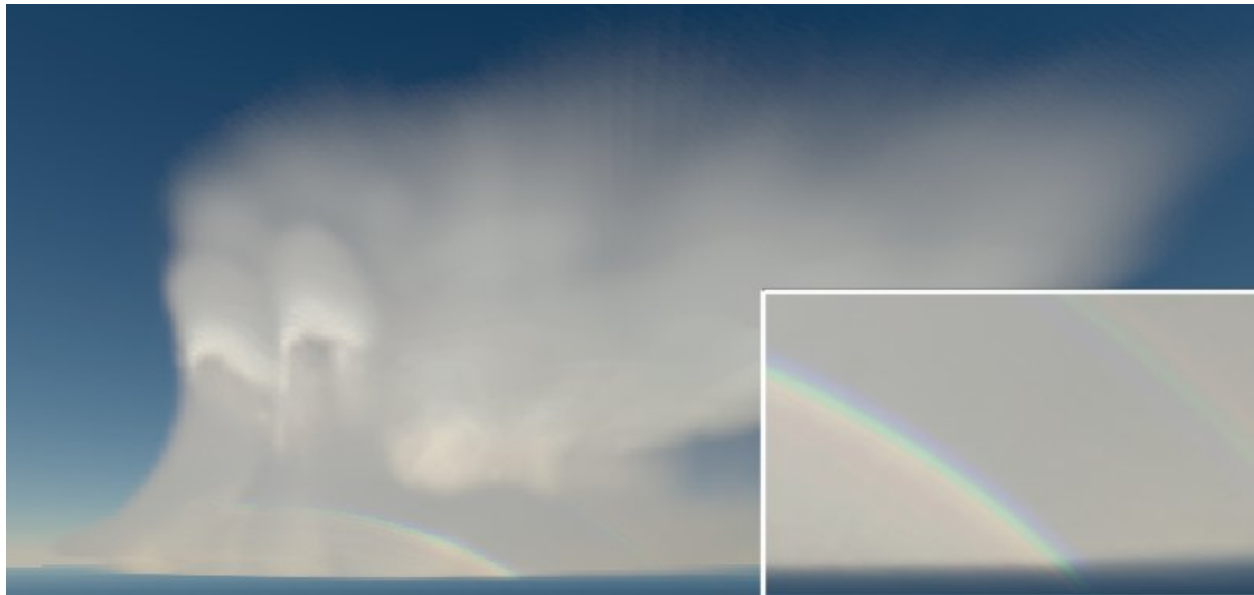
Computer rendering of a supercell storm modeled with the WRF model, using a new visually-accurate rendering system. A supercell storm was generated using the WRF mass core, and this image of the hydrometeor fields was rendered using Mr. Kirk Riley's (Purdue University) beta test display software.

The Morning Convection Project
Hane, Andra, **Carr**, **Trammel**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop a tool to help forecast the evolution of warm season MCSs that affect the central and eastern United States during late morning; gain a better understanding of the environmental factors that influence the evolution of these systems.

Accomplishments
Previous research developed a climatology of 145 morning MCSs during the 1996-2000 period and identified a subset of 48 systems for which environmental information was obtained through extraction of soundings from the RUC archive. Numerous scatter diagrams were produced to deduce the effect of pairs of environmental parameters on system evolution. This approach was extended by applying multivariate discriminant analysis to this data set using both two and three variables to discriminate between classes of evolution. These approaches have shown promise in forming the basis of a new research tool. An effort to produce such a tool is now beginning at the Norman NWS Forecast Office.

A proposal was written to COMET early in the year to fund an NWS Cooperative Project that would extend the climatology of these systems over more years, and produce more cases to add to the data base used to assess environmental influences. Preliminary indications are that this proposal will be funded, though we await the final word.

Publications:

Hane, C.E., J.D. Watts, D. L. Andra, Jr., J. A. Haynes, E. Berry, R. M. Rabin, F. H. Carr, 2003: The evolution of morning convective systems over the U. S. Great Plains during the warm season. Part I: The forecast problem. *Wea. Forecasting*, **18**, 1286-1294.
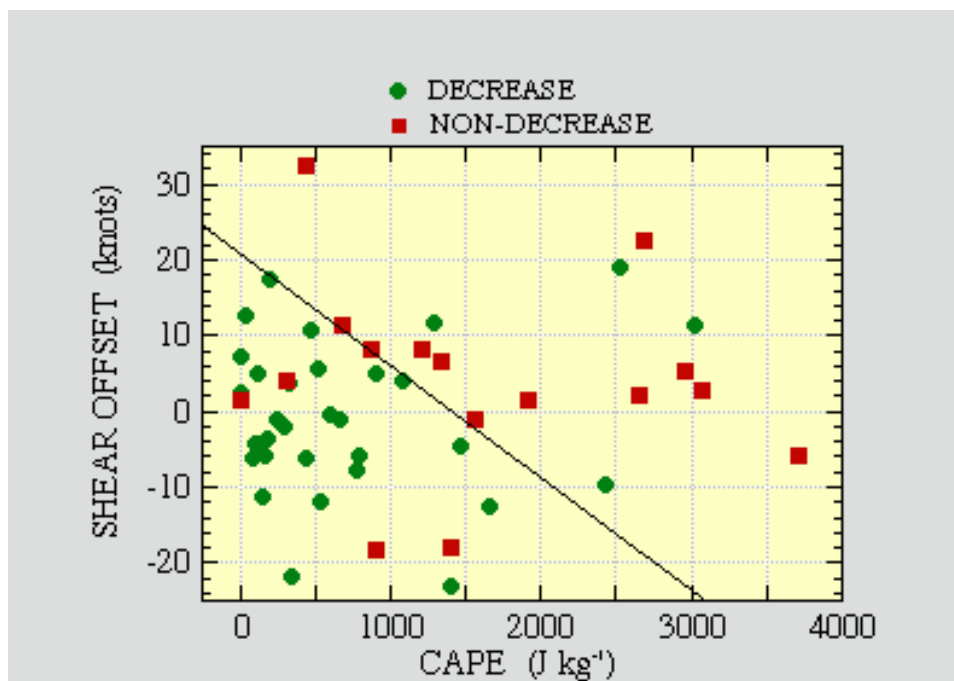
Scatter diagram of two classes of evolution (squares and circles) as a function of CAPE (J kg^{-1}) and shear offset (kts). Shear offset is a measure of the deviation of the shear vector between 600 and 350 hPa from the system motion direction. The diagram indicates that 75% of the cases above and to the right of the straight line fall in the "steady" evolution class, whereas 88% of the cases below and to the left of the line fall in the "decreasing-dissipating" class.

Land-Atmosphere Memory Quantified Using Observations from the Oklahoma Mesonet and the NOAH Land Surface Model

Basara. **Crawford**, Illston, Nemunaitis, Monroe, Hunt

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives

Develop a quality controlled data set which involves meteorological and hydrologic observations from Oklahoma Mesonet sites and obtain new insights of land-atmosphere interactions from diagnostic studies using Mesonet data; identify the parameterizations in the NOAH LSM which are sensitive to land surface conditions and use Mesonet data to modify, improve, and test the parameterizations to produce reduced model variability.

Accomplishments

A major accomplishment of Year 2 activities was the maturation of the NOAH validation study utilizing Oklahoma Mesonet data. Using retrospective simulation data from the NOAH LSM provided by the NLDAS Group, surface energy fluxes were simulated for the summer of 2000. The model simulated energy fluxes were compared with OASIS surface data for net radiation, downwelling shortwave radiation,

upwelling shortwave radiation, downwelling longwave radiation, upwelling longwave radiation, latent heat flux, sensible heat flux, ground heat flux, and surface skin temperature. The datasets from 2000 chosen for analysis of the simulated components of the surface energy budget used OASIS data from the following days: 23 May, 29 May, 30 May, 10 July, 13 August, 14 August, 25 August, and 29 August.

A manuscript entitled "Seasonal to Interannual Variations of Soil Moisture Measured in Oklahoma" (*International Journal of Climatology*, in press) describes use of the soil moisture network of the Oklahoma Mesonet to demonstrate the temporal and spatial variations of soil moisture in Oklahoma. An analysis of time series plots of soil moisture revealed four distinct soil moisture phases (moist plateau, transitional drying, enhanced drying, and recharge). The characteristics of each phase were identified via the physical processes that govern soil moisture. The moist plateau phase (November to mid-March) demonstrated how low evaporation, predominately cloudy skies, and dormant vegetation resulted in increased soil moisture with minimal fluctuations. The transitional drying phase (mid-March to mid-June) revealed the battle between forces removing moisture from the soil (evapotranspiration) and replenishing moisture to the soil (precipitation). The enhanced drying phase (mid-June to late August) displayed the dramatic decrease in soil moisture levels caused by increased evapotranspiration and decreased precipitation. The recharge phase (late August to November) demonstrated how fall precipitation and reduced biomass from harvesting increases the moisture levels in the soil to complete the cycle.

Publications

Fiebrich, C. A., J E. Martinez, J. A. Brotzge, and J. B. Basara, 2003: The Oklahoma Mesonet's skin temperature network. *J. Atmos. Oceanic Tech.*, **29**, 1496-1504.

Illston, B.G., J.B. Basara, and K.C. Crawford, 2003: Seasonal to interannual variations of soil moisture measured in Oklahoma, *Int. J. Climatol*, in press.

Illston, B. G., J.B. Basara, C. Fiebrich, M. Wolfingbarger, G. McManus, and D. Arndt. 2004: Real-time soil moisture Information for drought monitoring and assessment. *Preprints, 14th Conference on Applied Climatology*, Seattle, WA, Amer. Meteor. Soc.

Nemunaitis, K. L., J. B. Basara, B. A. Cosgrove, D. Lohmann, K. E. Mitchell, and P. R. Houser, 2004: Validation of the North American Land Data Assimilation System (NLDAS) using data from Oklahoma Mesonet OASIS sites. *Preprints, 18th Conference on Hydrology*, Seattle, WA, Amer. Meteor. Soc.

Robock, A., L. Luo, E. F. Wood, F. Wen, K. E. Mitchell, P. R. Houser, J. C. Schaake, D. Lohmann, B. A. Cosgrove, J. Sheffield, Q. Duan, R. W. Higgins, R. T. Pinker, J. D. Tarpley, J. B. Basara, and K. C. Crawford, 2003: Evaluation of the North American Land Data Assimilation System over the Southern Great Plains during the warm season. *J. Geophys. Res.*, **108(D22)**, 8846, doi:10.1029/2002JD003245.

Noah Surface Fluxes
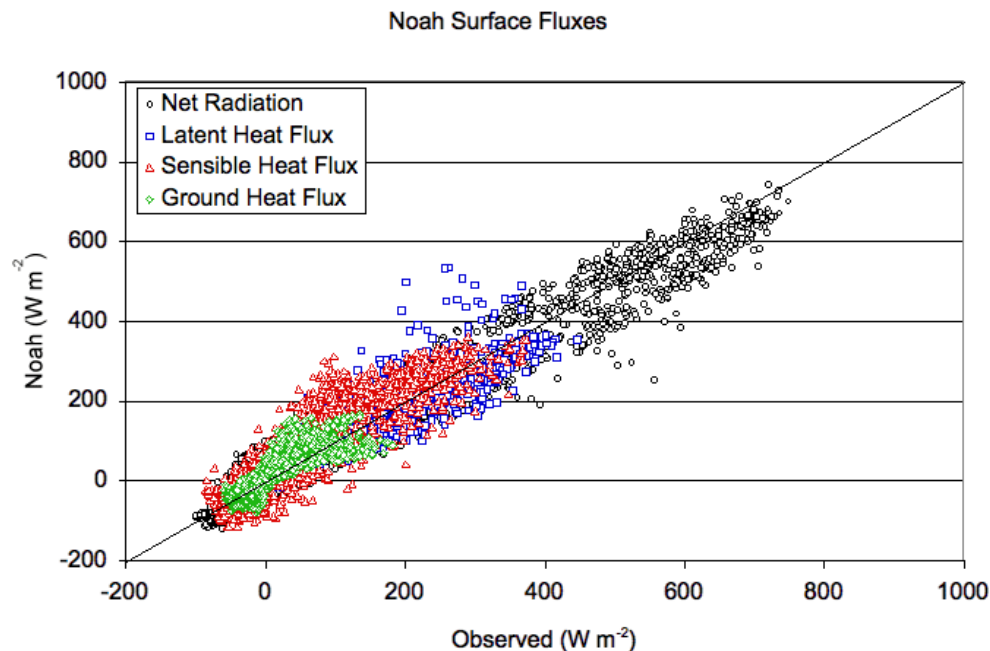
Scatter plot of the surface fluxes at OASIS Super Sites and corresponding NOAH model grid points. In terms of a regional approach to validating the NOAH land surface model, these results show that net radiation is captured very well, sensible heat flux is overestimated, latent heat flux is underestimated, and ground heat flux was slightly overestimated.

Heat Burst Studies
Trammell

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Identify radar echo structures common to the onset of heat burst activity in the Great Plains.

Accomplishments
Historically, heat bursts have been one of the least studied and most misunderstood potentially destructive atmospheric phenomena. Typically, heat bursts result from decreasing or collapsing areas of precipitation and are characterized by a sharp surface air temperature increase and relative humidity fall. Strong and gusty winds are commonly observed with heat burst activity, sometimes producing considerable tree and structural damage and causing a hazard to aircraft in the area. Until recently, relatively few heat bursts have been detected due to their small temporal and spatial scale in comparison with the national synoptic observational network. The implementation of several permanent mesoscale observing networks has increased the frequency of detections, dispelling the perceived notion that heat bursts are rare events and allowing for more in-depth study of these episodes. This resulting increased awareness has served to increase the importance of forecasting their onset, due to their associated hazards to life and property.

To date, the study of heat bursts has focused generally on surface perturbations created by the bursts, with limited attention given to the radar echoes in the vicinity and the vertical thermodynamic structure of the surrounding environment. Work completed in a Masters thesis addresses the two latter concepts, with the radar analysis being the primary focus. Radar data have been obtained from the WSR-88D Level II archives at the National Climatic Data Center (NCDC), which occupy over half the facility's storage space. Due to the large volume of radar data, it is increasingly important that the data be archived in an easily accessible and useable manner for meteorological applications. To explore the issue and to illustrate how Level II archives might be used in meteorological research, NCDC sought and supported this study using the Level II portion of the radar archives.

Investigation of WSR-88D data for 114 heat burst cases has uncovered five distinct precipitation system organization types, six reflectivity structures, and three radial velocity signatures that accompany heat burst activity. Several other unique reflectivity features also are discerned. Each of the radar characteristics is described in detail, including frequency of occurrence, vertical extent, and range biases. In addition to radar analysis, a composite proximity sounding has been calculated and analyzed to characterize a typical atmospheric profile conducive to heat burst activity. Using the concepts of Situation Awareness, the results from the radar and sounding analyses are combined to produce a concise and efficient heat burst forecast strategy for operational meteorologists. Contained in the forecast methodology are suggested environmental variables and types of Doppler radar images to examine and consider, as well as recommended courses of action based on the appearance of various environmental and radar features.

The use of Level II data also uncovered some data quality issues in the archives, namely range folding in the radial velocity measurements, ground clutter echo contamination, and missing or corrupted data. Suggestions for improving access to and use of the archives include the following – addition of header-type information to the data ordering webpage detailing various data attributes, such as Volume Coverage Pattern and valid data times; documentation of incomplete data; and development of user friendly viewing software requiring minimal data preprocessing and capable of reducing data errors such as velocity aliasing and ground clutter echo.
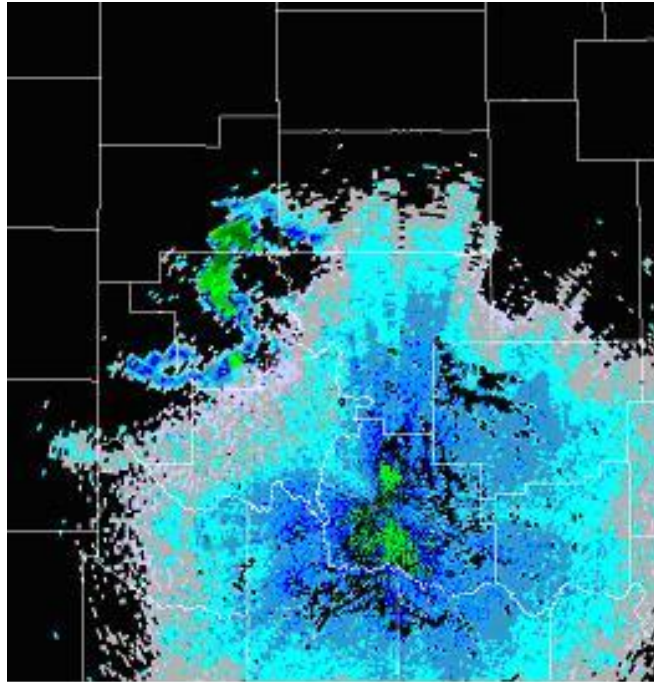
A prevailing reflectivity structure for heat bursts.

COMET COMAP Course
Burgess, Reader

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Serve as Scientific Lead for the COMET COMAP Course, and, with operational co-leads, manage the course; develop and deliver several lectures to the course; manage several laboratory sessions associated with the lecture material.

Accomplishments
The COMET COMAP course was held at COMET/UCAR from 6 October to 21 November 2003. Fifteen NWS Science Operations Officers attended the course. They were given graduate-level instruction on many topics in mesoscale meteorology, research techniques, and personnel management. Approximately 20 nationally known researchers from UCAR/NCAR, OU, and other universities lectured the students. Course reviews suggested that course materials were well-received.

Contribution to the WRF Model Development by CAPS
Xue, Gao, Brewster, Ren, **Liu**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop the radar data assimilation components for the WRF 3DVAR system; develop a 4DVAR based soil temperature and moisture retrieval system for use in mesoscale models and improve land surface models; contribute to the development and testing of WRF model system.

Accomplishments

Accomplishments include the further development and testing of radar data assimilation components to be used in the WRF 3DVAR system (Gao et al 2004a) and the application of the 3DVAR system for the initialization of a convective storm (Hu et al 2004a,b); the development of wind profile retrieval technique from radar data (Gao et al 2003, 2004b,c) and a variational 4DVAR system for retrieving soil model initial conditions and model parameters (Ren and Xue 2004b, Ren 2004); and improvement to the force-restore model used in land surface models (Ren and Xue 2004a). Additional work was done in developing a system for assimilating radar and other data based on the ensemble Kalman filter technique (Tong and Xue 2004). We also ported the NCEP Grid-point Statistical Interpolation (GSI) package to our local machine and will add radar data assimilation capabilities to the system.

Publications

Gao, J., M. Xue, K. Brewster, and K. K. Droegemeier, 2004a: A three-dimensional variational data assimilation method with recursive filter for single-Doppler radar, *J. Atmos. Oceanic. Technol.*, **21**, 457-469.

Gao, J., K. K. Droegemeier, J. Gong and Q. Xu, 2004b: Retrieval of vertical wind profiles from Doppler radar radial velocity data, *Mon. Wea. Rev.*, **132**, 1399-1409.

Gao, J., and K. K. Droegemeier 2004c: A wind profile retrieval method from azimuthal gradients of radial velocity, *J. Appl. Meteor.* , **43**, 934-940.

Gao, J., K. K. Droegemeier, J. Gong and Q. Xu, 2003: A wind profile retrieval method from azimuthal gradients of radial velocity, *Preprints, 31th Conf. on Radar Meteorology*, Amer. Meteor. Soc., 339-342.

Hu, M., M. Xue, and J. Gao, 2004a: 3DVAR and cloud analysis with WSR-88D Level-II data for the prediction of March 28-29, 2000 Fort Worth tornadic thunderstorms. Part I: Impact of 3DVAR radial wind analysis. *Mon. Wea. Rev.*, to be submitted.

Hu, M., M. Xue, and K. Brewster, 2004b: 3DVAR and cloud analysis with WSR-88D Level-II data for the prediction of March 28-29, 2000 Fort Worth tornadic thunderstorms. Part II: Impact of cloud analysis. *Mon. Wea. Rev.*, to be submitted.

Ren, D., 2004: 4DVAR Retrieval of Prognostic Land Surface Model Variables, Ph. D. Dissertation, School of Meteorology, University of Oklahoma, 228 pp.

Ren, D., and M. Xue, 2004a: An improved force-restore model for land-surface modeling, *J. App. Meteor.*, in press.

Ren, D. and M. Xue, 2004b: 4DVAR assimilation of ground temperature for the estimation of soil moisture and temperature. *Preprints, 20th Conf. Wea. Anal. Forecasting/16th Conf. Num. Wea. Pred.*, Amer. Meteor. Soc., Seattle, WA.

Tong, M. and M. Xue, 2004: Ensemble Kalman filter assimilation of Doppler radar data with a compressible nonhydrostatic model: OSSE Experiments. Mon. Wea. Rev., accepted.

Climatic Effects of/Controls on Mesoscale Processes

Investigation of the Large-Scale Atmospheric Moisture Field over the Midwestern United States in Relation to Summer Precipitation
Zangvil, **Portis**, **Lamb**

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Investigate land-atmosphere interactions on different time-scales over the agriculturally important Midwest using: moisture budget analysis; an original recycling technique developed by Zangvil; crop yields; and soil moisture and solar radiation data.

Accomplishments
A land-atmosphere interaction problem of utmost environmental importance involves the classical issue of the relative contributions to regional precipitation of locally evaporated and transpired (i.e., recycled) moisture versus externally advected atmospheric water vapor. Using a recycling formula that was developed by Zangvil, along with an analysis of daily atmospheric moisture budget estimates, and the development of three additional sets of environmental data (solar radiation, soil moisture, crop yields), we attempted to interpret the complex land-atmosphere interactions involved in terms of plant behavior, solar radiation forcing, and challenging time-scale interrelations over the agriculturally important Midwest. Our results confirm the widely held view that land-atmosphere interactions are involved intimately in pronounced seasonal, regional climate anomalies. This confirmation did not emerge from a more conventional analysis that was limited to seasonal and monthly time-scales. The role of deficient precursor soil moisture was confirmed for strikingly low PE/P (recycling ratio) and E (evaporation) values obtained for days in 1988 when area-averaged precipitation (P) varied from 0.6 mm to 8 mm.

Publications
Zangvil, A., D. H. Portis and P. J. Lamb, 2004: Investigation of the large-scale atmospheric moisture field over the Midwestern United States in relation to summer precipitation. Part II: Recycling of local evaporation and association with soil moisture and crop yields. *J. Climate*, **17**, 3283-3301.
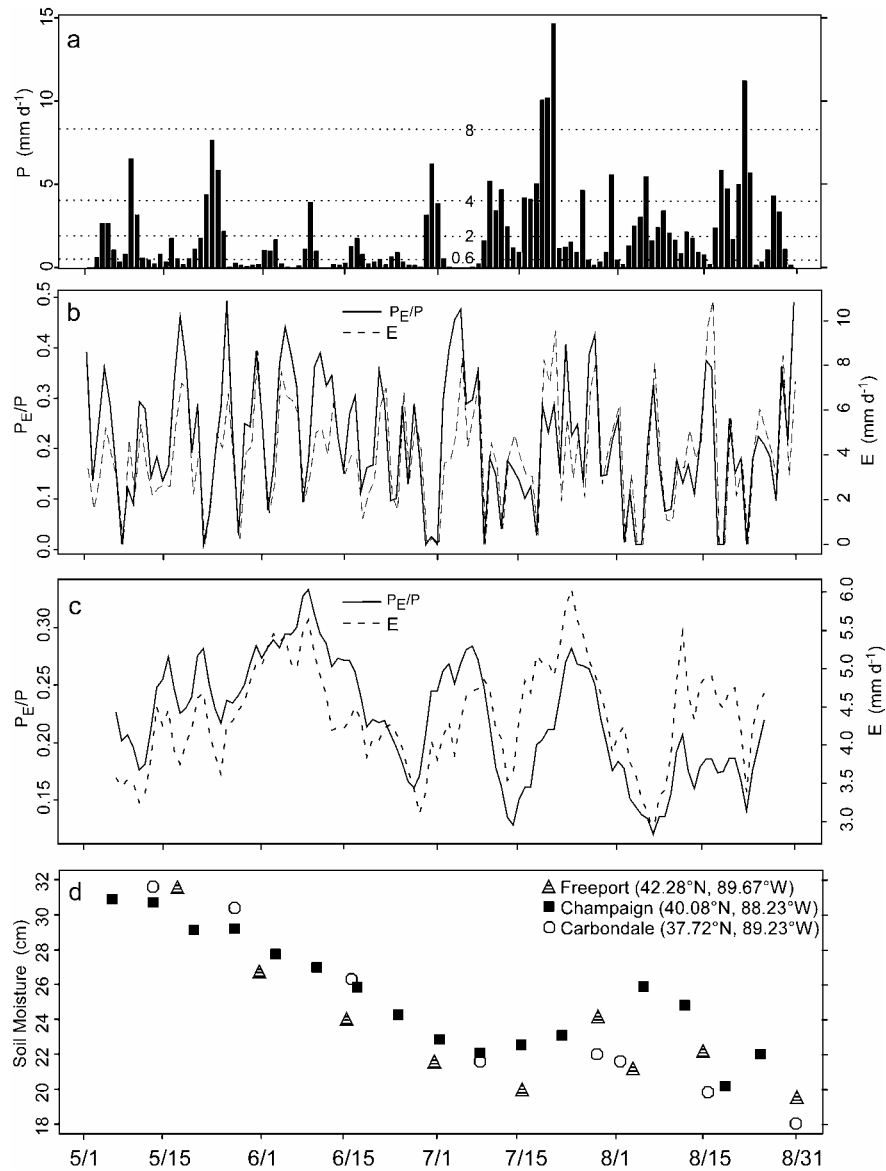
Multi-paneled plot showing selected area-averaged moisture budget components and soil moisture measurements over the very dry 1988 summer. Shown is the seasonal march (month/day) of (a-c) the area-averaged precipitation (P), recycling ratio (PE/P) and evaporation (E) for our study region (mm d-1 or dimensionless) and (d) soil moisture for three Illinois stations (cm). Panels a and b have 24-hr resolution; panel c contains 10-day running means of time series in panel b; values in panel d are instantaneous neutron probe measurements made on days indicated.

North Atlantic Climate Variability
El Hamly, Lamb, Portis

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Study the spatial and temporal variability of cyclones over the North Atlantic basin.

Accomplishments

Not only do cyclones in the North Atlantic strongly influence the weather and climate of surrounding areas such as eastern U.S., eastern Canada, southern Greenland, Iceland, Western Europe, the Mediterranean Basin, and northwest Africa, but their influence also extends beyond the Atlantic basin. Their global influence is linked to the role of storm tracks for in-situ freshwater flux into the oceanic gyres that drive the global thermohaline circulation. This project developed a new approach to study cyclones by constructing a cyclone density function (CDF) on a 2ºx2º grid for winter (October-March) cyclones as identified by Serreze's cyclone tracking density function from 1948-1999. This approach allows one to study cyclones characteristics (e.g. location, sea level pressure tendency, intensity and moving speed) simultaneously in space and time. Previous studies have averaged cyclone characteristics in either space or time. The CDF was analyzed on different timescales in relation to different teleconnections (e.g. NAO and ENSO) and for dominant spatial patterns based on EOF analysis. Mostafa El Hamly successfully defended this research during 2003-2004 and received his doctorate from the University of Oklahoma.

Publications

El Hamly, M, 2004: North Atlantic Winter Surface Extratropical Cyclone Track Variability on Interannual-to-Decadal Time-Scales. Ph.D. dissertation, The University of Oklahoma, 305 p.
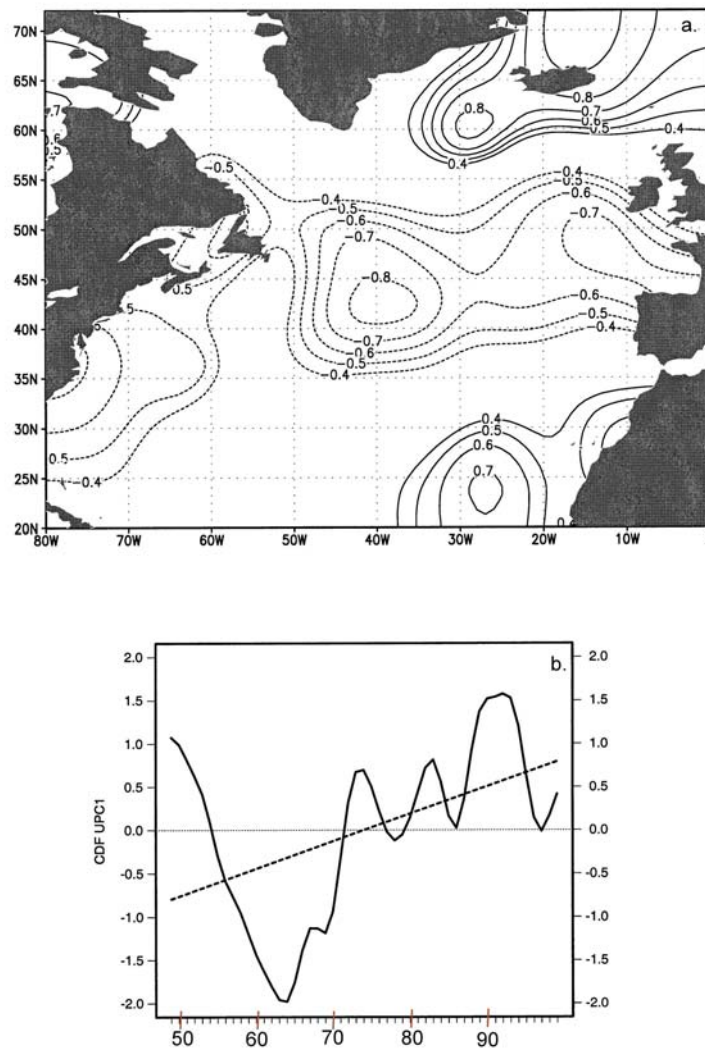
Pattern analysis results for low frequency North Atlantic winter CDF anomalies: a) spatial loading pattern for the first unrotated principal component mode (UPC1) and b) the standardized score time series associated with the above UPC1. Linear trend is indicated by the broken line. This figure indicates that the 1950's and 1960s had a zonal storm track, but at the end of the 1960s, the cyclones had a northeastern track over the Greenland Sea.

80

Dynamics of the West African Intertropical Front and its Relationship to Sahelian Summer Rainfall Variability
Issa Lele, Lamb

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Examine and understand the intraseasonal variations of rainfall patterns over Sahelian countries within the framework of the dominant influence of the Intertropical Front and the deep convergence zone.

Accomplishments
This new Ph.D. effort started during the fiscal year. A literature review has been completed, as well as the collection and digitizing of daily observations for some countries in West Africa.

Socioeconomic Impacts of Mesoscale Weather Systems and Regional Scale Climate Variations

Energy Indices
Timmer, Lamb

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Develop monthly and seasonal residential natural gas consumption indices east of the Rocky Mountains.

Accomplishments
The U.S. Department of Energy divides the U.S. into Petroleum Administration for Defense Districts (PAD Districts, or PADDs) for planning purposes and organization of historical energy data. The PAD Districts east of the Rocky Mountains were used in this study and were further subdivided into 9 sub-PADD regions for which the natural gas demand indices were calculated. Monthly and seasonal residential natural gas consumption indices were derived for each sub-PADD based on state averages of monthly/seasonal total number of days below site-specific, daily maximum and minimum temperature percentile thresholds. Disparate indices were calculated for daily maximum and minimum temperature percentiles so that the relative effect of daily maximum and minimum temperature on monthly natural gas consumption could be analyzed. Natural gas consumption indices were derived for the 2nd through the 80th daily maximum and minimum temperature percentiles at 2 percent intervals to determine the percentile threshold of both daily maximum and minimum temperature that "drives" natural gas consumption. The monthly and seasonal natural gas consumption indices were calculated for both 3-month and 4-month winter seasons, with the 4-month winters including the months of January, February, November, and December, and the 3-month winters excluding November.

Significant correlations between the temperature percentile threshold indices and residential natural gas consumption (monthly indices were correlated to monthly anomalies of natural gas consumption to remove the monthly variability) were achieved for most sub-PADDs and weighting methods. Overall, indices based on monthly and seasonal totals of days below daily maximum temperature thresholds yielded higher correlations than did the indices based on daily minimum temperature thresholds, although the index with the highest correlation of all the sub-PADD indices was based on a daily minimum temperature percentile threshold. The highest correlation of all the monthly sub-PADD indices was .9256, which was derived using the 38th percentile of daily minimum temperature, was non-weighted, and was based on 3-month winter seasons. The best correlation of all the seasonal monthly sub-PADD indices was .9869, which was derived using the 32nd percentile of daily minimum temperature, was non-weighted, and was based on 4-month winter seasons.

The nine sub-PADD regions east of the Rocky Mountains.

Economic Impacts Research
Sutter, Simmons, Merrell, Sadowski

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
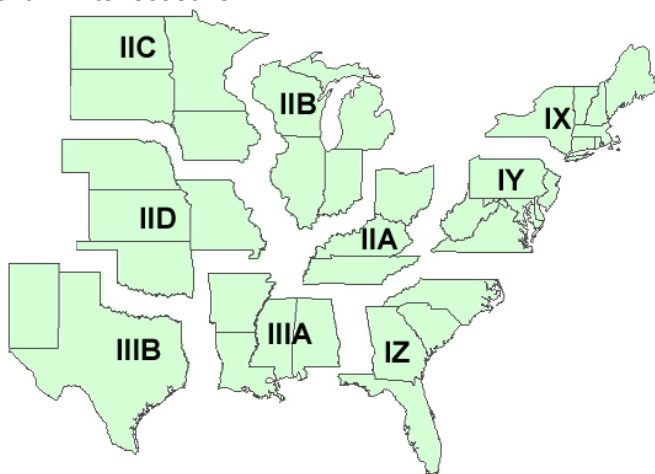Study the economic impacts of tornadoes and hurricanes.

Accomplishments
Tornado Shelters. In "The Determinants of Tornado Casualties and the Benefits of Tornado Shelters" (co-authored with Kevin Simmons and David Merrell, forthcoming in Land Economics), we use tornado data from Oklahoma to quantify the benefits of tornado shelters in permanent homes and mobile homes. We use both historical fatalities and predicted fatalities from a regression model of tornado casualties to determine the number of fatalities and injuries that might be avoided with shelters. We found that the cost per life saved for shelters in permanent homes is quite high, over $30 million without discounting, and over $50 million with a 3 percent real discount rate. However, shelters in mobile home parks offer protection at a cost of less than $5 million per life saved, even with a 3 percent discount rate. These calculations have been extended to other states using historical data on fatalities.

In a new working paper "Direct Estimation of the Cost Effectiveness of Tornado Shelters" (co-authored with Kevin Simmons), we estimate the cost per life saved using estimates of the annual probability of a tornado plus the probability of a fatality at a home struck by a tornado. This provides an alternative method to estimate the cost effectiveness of shelters. We find for Oklahoma that this cost is within 10 percent of the amount calculated based on total fatalities.

Tornado Casualties. In "WSR-88D Radar, Tornado Warnings and Tornado Casualties" (co-authored with Kevin Simmons), we attempt to quantify the safety benefits with respect to tornadoes of the installation of Doppler radar by the NWS. We perform a before-and-after analysis of Doppler radar using a regression model of tornado casualties and a data set of all tornadoes in the contiguous U.S. between 1986 and 1999. We found that after Doppler radar installation the expected fatalities from a tornado were 45 percent lower and expected injuries 40 percent lower than prior, with both of these results being statistically significant. We also found that the percentage of tornadoes warned for increased by 70 percent and the mean lead time on tornado warnings increased by 80 percent following Doppler radar installation.

In "Protection from Nature's Fury: An Analysis of Fatalities and Injuries from F5 Tornadoes" (co-authored with Kevin Simmons) we perform a regression analysis of casualties from F5 tornadoes over the 20th century to see if we can confirm that tornadoes have become less deadly over time. Over the period 1950 to 1999, during which we can control for income, we found that expected fatalities have fallen by 41 percent and expected injuries by 13 percent, and that these results are statistically significant. With income controlled for, we are relatively confident our time trend variable is capturing changes in morbidity due to improved warnings and public awareness. Over the period 1900 to 1999, expected fatalities fell by 91 percent and expected injuries by 37 percent, but since changes in income cannot be controlled for, we cannot attribute all of this change to improved warnings and awareness.

Societal Vulnerability. In "Hurricane Fatalities and Hurricane Damages: Are Safer Hurricanes More Destructive?" (co-authored with Nicole Sadowski), we examine a possible cause of increasing societal vulnerability to hurricanes – the reduction in the lethality of hurricanes. As hurricanes become less deadly, this lowers the full cost of living on hurricane-prone coasts and should increase coastal populations and damage amounts. We confirm this prediction with a two-stage regression analysis in which we estimate a time-varying measure of hurricane lethality and then show that this measure significantly increases damage from hurricanes.

Publications

Merrell, D., Simmons, K. M., and Sutter, D., 2005: The Determinants of Tornado Casualties and the Benefits of Tornado Shelters. *Land Economics*, accepted.

Ridley, W. L., Simmons, K. M., and Sutter, D., 2004: The Market for Tornado Protection: Market and Policy Responses following the May 1999 Oklahoma Tornadoes, *Economics and Wind*, edited by B. T. Ewing and J. B. Kruse, Nova Science Publishing, accepted.

Sadowski, N., and Sutter, D., 2004: Natural Hazards, Fatality Rates and Societal Vulnerability, *Economics and Wind*, edited by B. T. Ewing and J. B. Kruse, Nova Science Publishing, accepted.

Simmons, K. M., and Sutter, D., 2004: WSR-88D Radar, Tornado Warnings and Tornado Casualties. *Wea. Forecasting*, submitted.

Simmons, K. M., and Sutter, D., 2004: Protection from Nature's Fury: An Analysis of Fatalities and Injuries from F5 Tornadoes, *Natural Hazards Review*, submitted.

Sadowski, N., and Sutter, D., 2004: Hurricane Fatalities and Hurricane Damages: Are Safer Hurricanes More Destructive? *Southern Economic Journal*, submitted.

Multiscale Evolution and Predictability of a Warm Season Climate Anomaly in the U.S. Southern Great Plains
Nutter, Leslie, Lamb

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives

Understand the physical and dynamical processes responsible for creating an intraseasonal cool anomaly over the U.S. Southern Great Plains during summer 2002; identify predictable characteristics of the anomaly to help improve forecasts of similar reoccurrences at lead times exceeding 10 days, thereby helping to mitigate social and economic losses.

Accomplishments

Surface and upper-air observations obtained from locations across the U.S. Southern Great Plains were combined with NCAR/NCEP reanalyses to reveal how a series of related severe weather events led to an historic flood near San Antonio, Texas, during summer 2002. The flood is shown to have initiated regional-scale processes that helped maintain a six-week period of anomalously cool weather over Texas and Oklahoma. For example, there was evidence of a positive feedback cycle between enhanced soil moisture and reduced surface temperature in association with the cool anomaly. However, this commonly recognized feedback cycle does not appear to be the fundamental mechanism helping to maintain the anomaly. Rather, a new decomposition of temperature and moisture advection reveals a dipole structure that persists through the duration of the cool anomaly. The advection term is decomposed into four terms showing the nonlinear interaction between the seasonal anomalies and the long-term mean fields. The figure below shows an example of the dipole structure associated with the advection of the temperature anomaly by the long-term mean wind field, averaged over indicated half-monthly periods. A similar dipole pattern is revealed in specific humidity, but not in the velocity fields (not shown). This result suggests that, once created by the Texas flood, processes associated with temperature and moisture were more important in maintaining the regional anomaly than were variations in the wind field caused by the passage of weak synoptic systems.

The existence of the advection dipole pattern is significant because it helps to support and maintain the anomaly by aligning with the existing long-term mean summer advection pattern. The diagnostic does not reveal sources or sinks of moisture and temperature, but does indicate whether existing anomalies will be strengthened (weakened) by interacting positively (negatively) with the long term mean flow. A non-destructive dipole advection pattern could become an important identifiable feature of long-lead predictions for recurring intraseasonal anomalies in the future. Continuing work will determine if the advection anomaly dipole was present in long-lead forecasts of this event to assess its utility in prediction.

Publications

Nutter, P. A., L. M. Leslie, and P. J. Lamb, 2004: Multiscale evolution and predictability of a warm season climate anomaly in the U.S. Southern Great Plains. *Preprints, 15th Symposium on Global Change and Climate Variations, 1.2*, Amer. Meteor. Soc., Boston. CDROM.
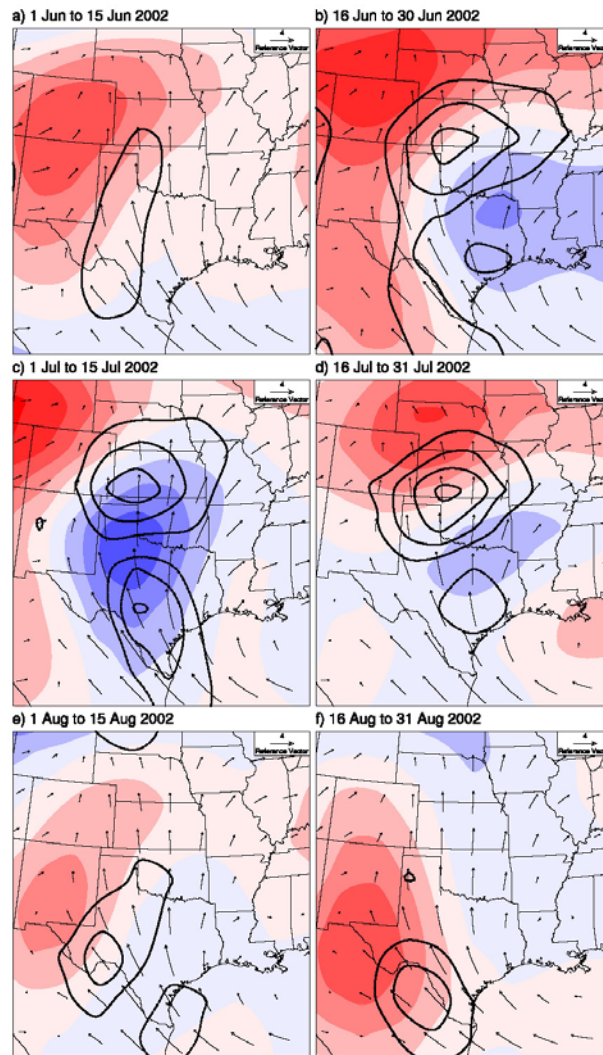
a) 1 Jun to 15 Jun 2002   b) 16 Jun to 30 Jun 2002

c) 1 Jul to 15 Jul 2002   d) 16 Jul to 31 Jul 2002

e) 1 Aug to 15 Aug 2002   f) 16 Aug to 31 Aug 2002

Dipole structure associated with the advection of the temperature anomaly by the long-term mean wind field, averaged over indicated half-monthly periods. Shown are the half-monthly averaged 925 hPa temperature anomaly, long-term mean velocity vectors, and advection of temperature anomaly by the long-term mean wind. Temperature anomalies are shaded from cool (blue) to warm (red) with increments of one degree Celsius. Solid (dashed) contours show positive (negative) advection at 0.00001 deg/s increments.

Rainfall and Agriculture in Central West Africa since 1930
Dibi, Lamb

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Examine rainfall variability and its effects on crops, societies, and economies of Mali, Burkina Faso, and Côte d'Ivoire.

Accomplishments
Sub-Saharan West African rainfall is highly variable. This variability is related to changes in the tropical Atlantic sector and circulation regimes that alter the preferred location of tropical convection along with the Intertropical Convergence Zone. Rainfall variations and their influence on crops need to be assessed.

Although many studies have been conducted on the effects of rainfall on agriculture in various parts of the world, few studies have focused on Central West Africa. This study examines rainfall variability and its effects on crops, societies, and economies of Mali, Burkina Faso, and Côte d'Ivoire.

Rainfall is critical in determining agricultural output. Most farming systems and many aspects of crop growth are adversely affected by rainfall variability, which can have a disproportionate impact because individual crops are affected differently. Agriculture is the main mode of employment, especially in rural areas; thus, the socioeconomic well-being of Central West Africa relies on crop cultivation, which strongly depends on rainfall.

This analysis also investigates rainfall/crop yield relationships. The temporal focus is on recent decades spanning 1930-1998; adjustments are made as the available data lengths require. The aim is to determine whether rainfall fluctuations are associated with changes in crop productivity. Additionally, this study of rainfall/crop yields helps to better understand the environment, society, and economy of Central West Africa.

Results suggest that rainfall variations adequately account for more of the crop output than do environmental policies. It is concluded that the main influence on agriculture is rainfall; thus, crop yields revolve mainly around the occurrence or non-occurrence of rains. Consequently, the understanding of rainfall variability and its induced agricultural changes is a necessity for sustainable socioeconomic development in Mali, Burkina Faso, and Côte d'Ivoire. This study recommends that environmental policies should acknowledge the importance of seasonal rainfall forecasts and incorporate the climate aspects (i.e., agroclimatologic challenge) into agricultural productivity.

Doppler Weather Radar Research and Development

NSSL 2: Quantitative Precipitation Estimation and Segregation Using Multiple Sensors – QPESUMS Development and Improvement

Gourley, J. Zhang, Arthur, Clarke, Cox, Langston, Qin, Wang, Xia, Farmer, Donner

NOAA Strategic Goal 3 (Serve Society's Need for Weather and Water Information)

Objectives

Continue research and development leading to improved estimation of precipitation for flash flood monitoring and prediction, watershed management, inputs to hydrologic models and near storm-scale models, and for verification of high-resolution numerical weather forecasts.

Accomplishments

The recent availability of the Level-II radar data over the Internet has provided the capability of running the QPE SUMS algorithm over the conterminous U.S. A Linux cluster was purchased and configured to import all data sources relevant to QPESUMS. The full suite of QPESUMS precipitation estimates is presently being produced on two tiles, with the intention of populating all tiles in the U.S. as soon as computer resources become available. Several operational NWS forecast offices and river forecast centers have been made aware of this project. As a result, we have determined the proper format and supplementary data description files needed for our products to be displayed in the AWIPS system.

Several basic developments to the core algorithm have been accomplished in the last year. A new technique for segregating rain from snow using combined observations from radar and mesoscale model analyses was developed and deployed. Initial results indicate the method is successful over relatively flat and gently sloping terrain.

A great deal of emphasis has been placed on the algorithm structure to utilize accurate reflectivity measurements from the lowest, unobstructed elevation angle. The ingest component of QPESUMS was updated to account for new volume coverage patterns running on WSR-88D radars. There are some instances in which the beam occultation data do not represent the true power density-weighted beam blockages. These occultation calculations are computed from a 30-m digital elevation model at every radar site. Climatological reflectivity statistics are now being computed in real-time to identify regions that have incomplete coverage due to natural and man-made blockages (e.g., trees and towers) that are not represented in digital elevation models. These climatologies will be used to manually correct look-up tables to instruct the algorithm on which elevation angle is the closest to the ground, and is unblocked.

The accuracy of reflectivity measurements has been improved through robust quality control techniques. A new reflectivity quality control algorithm was developed based on horizontal and vertical reflectivity structure. The algorithm has been tested on over 200 volume scans of base level data from different radar sites and from different seasonal and diurnal times. The results show that the quality control algorithm is very successful in identifying non-precipitation echoes such as ground clutter, clear air and biological echoes.

A new automated 2D multi-pass velocity dealiasing algorithm has been developed and tested. The algorithm can correct for aliased Doppler velocity data properly in more than 99 percent of the cases (about 1000 volume scans) tested. The new algorithm is shown to be more robust than the current operational WSR-88D dealiasing scheme in regions near data voids and range folded observations.

Instances have been identified in which reflectivity data being mosaicked between adjacent radars differ in magnitude. This apparent miscalibration can lead to artificial boundaries at midpoints between radar locations. Software has been developed for ROC Hotline personnel to monitor such differences. This software has been used on several occasions to identify and correct radars that have drifted out of calibration.

Publications

Gourley, J. J. and N. Dotzek, 2004: The effects of vertical air motions on radar estimates of rainfall. *ERAD Publ. Ser. 2.*

Gourley, J. J., R. A. Maddox, and B. M. Clarke, 2004: A multisensor approach to partitioning convective from stratiform echoes. *ERAD Publ. Ser. 2.*

Gourley, J. J. and B. E. Vieux, 2004: Evaluating the accuracy of quantitative precipitation estimates from a hydrologic modeling perspective. *J. Hydrometeor.*, submitted.

Gourley, J. J. and B. E. Vieux, 2003: The effects of radar-derived rainfall uncertainties on forecasts from a distributed hydrologic model. *Weather Radar Information and Distributed Hydrological Modeling*, Intl. Assoc. of Hydro. Sci. Publ. no. 282, 130-137.
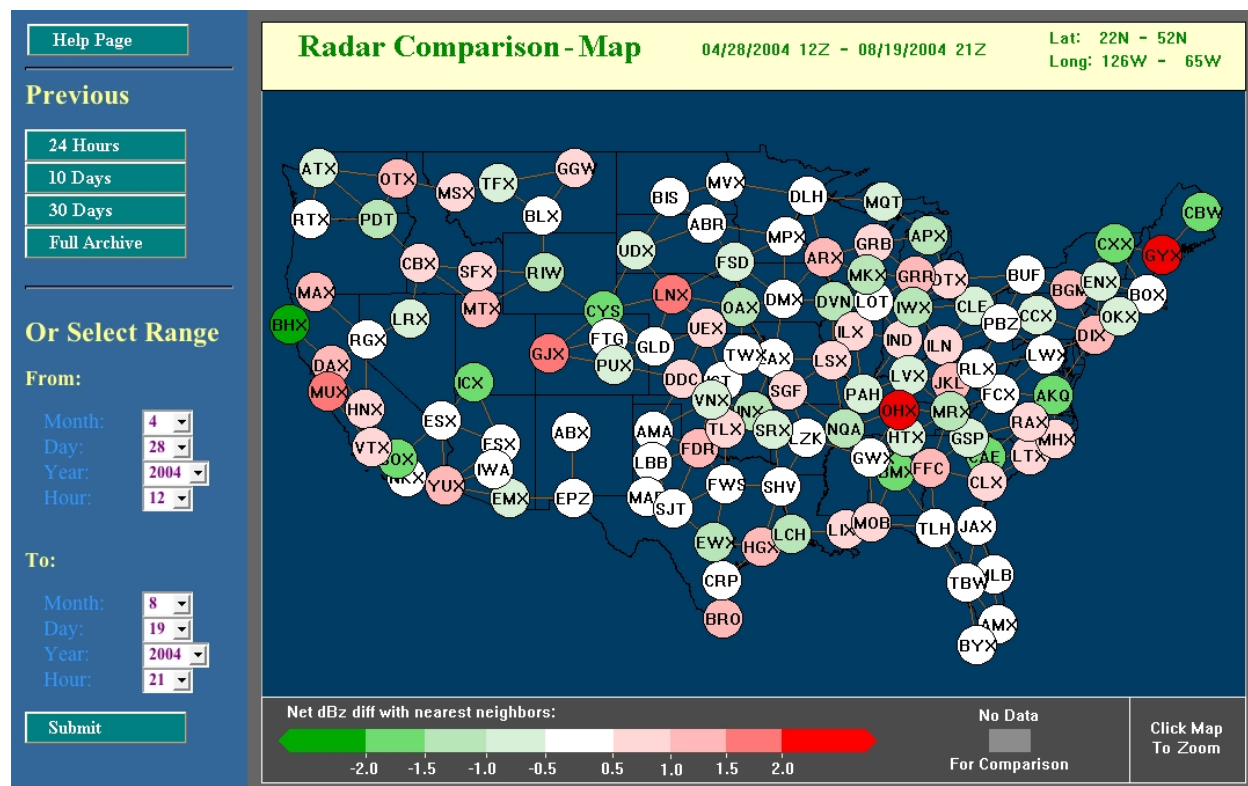
Image produced from software that was developed for ROC-Hotline personnel to monitor reflectivity differences between adjacent radars. This tool has been used operationally to identify and subsequently fix miscalibrated WSR-88D radars. Radars are colored according to their reflectivity comparisons over several months with adjacent radars. Red colors indicate the radar is relatively "hot", while green suggests the radar is relatively "cool".

NSSL2: Quantitative Precipitation Estimation and Segregation using Multiple Sensors – *National Mosaic and Multi-Sensor QPE (NMQ)*
J. Zhang, **Xia**, **Wang**, **Langston**, **Qin**, **Clarke**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives

Provide a seamless conterminous U.S. 3D radar reflectivity mosaic that has high spatial resolution (1km x 1km x 500m) and rapid update cycle (every 5 min) for severe weather applications and for mesoscale numerical weather model data assimilation; provide accurate conterminous U.S. precipitation estimates over a high-resolution (1km x 1km) grid with a rapid update cycle (every 5min) for flash floods and flood warnings, and for water resource management.

Accomplishments

A national 3D radar reflectivity mosaic system has been developed. The system includes components that perform reflectivity quality control, velocity dealiasing, 3D spherical to Cartesian grid transformation,

and weighted mean multiple radar reflectivity mosaic. The NMQ 3D mosaic is consistent and seamless while successfully retaining the high-resolution storm structure that is apparent in the raw radar observations. Real-time implementation and testing has shown that the mosaic system is stable and computationally efficient to reside as part of an operational system. The 3D grid can be useful for derived products such as high-resolution rainfall maps, severe storm identification products, hazardous weather products for aviation, and for data assimilations in convective scale numerical weather prediction models.

Publications

Zhang, J., K. Howard, and J.J. Gourley, 2004: Constructing three-dimensional multiple radar reflectivity mosaics: examples of convective storms and stratiform rain echoes. *J. Atmos. Ocean. Tech.*, accepted.

Zhang, J., K. Howard, W. Xia, and J.J. Gourley, 2003: Comparison of objective analysis schemes for the WSR-88D radar data. *Preprints, 31th Conference on Radar Meteorology*. 5-12 August 2003, Seattle, Washington, 907-910.
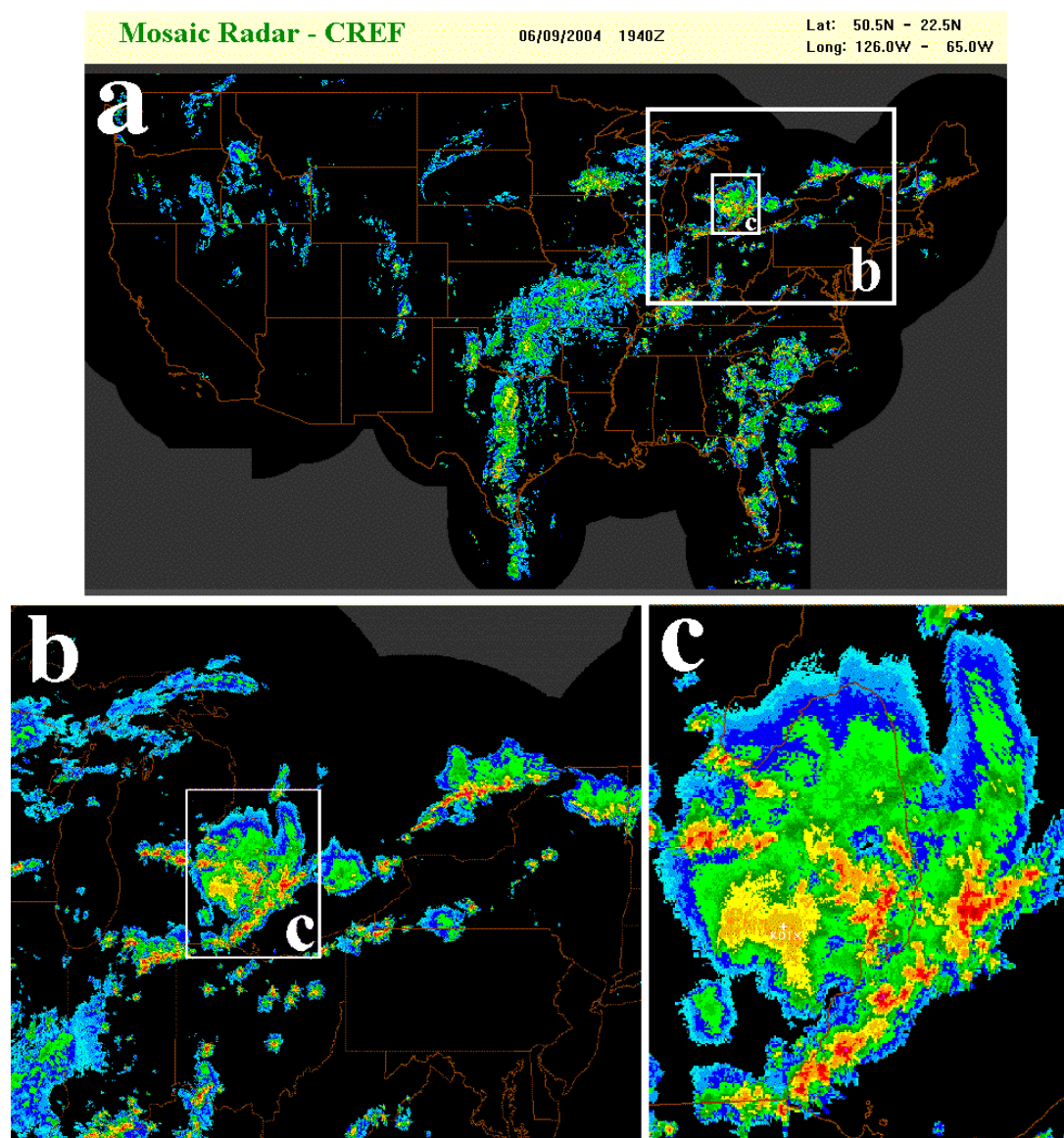
An example composite reflectivity image from the real time NMQ 3D mosaic (a) and two zoomed-in images for smaller regions (b and c). This example is from the very first 1-km mosaic product using Level-II data from 130 radars in real-time. The reflectivity field is largely free of non-meteorological echoes such as ground clutter, and clear air and biological returns. The mosaic field is consistent and seamless across umbrellas of different radars. The zoomed-in images (b and c) show detailed structure of storms in smaller regions, and is much better resolved than in NIDS products.

NSSL3: Severe Weather Warning Research and Application Development – *WSR-88D Applications and Algorithms*

Burgess, Farmer, Flickinger, **Gourley,** Kaney, **Lakshmanan, Manross, Smith**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives

Develop better WSR-88D applications/algorithms; transfer the technology (better applications/algorithms) to the ROC for NEXRAD Tri-Agency use.

Accomplishments

Progress has fallen into two areas: new algorithm development and new technique development. New algorithm development work has been done in two areas. The first involves expanding the previously-developed Mesocyclone Detection Algorithm (MDA) by adding a neural network that incorporates radar information and Near Storm Environment (NSE) information. NSE data may be added from any source; the current source is RUC zero hour assimilation output. New MDA outputs were created that give the probability of tornado occurrence for selected radar (reflectivity and velocity) parameters and selected environmental parameters. The figure below shows skill scores for the probability of tornado from best performing parameters. A second are of work has involved development of a data quality algorithm that compares reflectivity from all WSR-88D adjacent radar network pairs. The comparisons occur at equal ranges/heights from radar pairs. Input data come from the newly-started NWS real-time Level II data dissemination system IRaDS. The first version of this Cross-Radar Correlation Algorithm is being transferred to the ROC Hotline for evaluation.

New technique development has also been done in two areas. The first involves constructing and evaluating new Volume Coverage Patterns (VCPs) for the ORPG. A previously developed new VCP (from this project) became operational on WSR-88Ds during the reporting year. Three other new VCPs are being developed. A second thrust involves evaluation of different potential types of ORDA Super Resolution Data. Potential new data (0.5° azimuth and 250 m gate spacing for reflectivity) are being compared to legacy data (1.0° azimuth and 1 km gate spacing for reflectivity). Early indications are that the new super resolution data provide substantial benefit in severe storm diagnosis and warning preparation. The new technique development work has been done in association with the NEXRAD Product Improvement initiative.

Publications

Gourley, J.J., B. Kaney, and B. Maddox, 2003: Evaluating the calibrations of radars: A software approach. *Preprints: 31st Conf. Radar Meteorology*, AMS, 6-12 August, 2003, Seattle, WA, 459-462.

Brown, R.A., R.M. Steadham, B.A. Flickinger, and V.T. Wood, 2003: A new WSR-88D scanning strategy: Results of field tests. *Preprints: 31st Conf. Radar Meteorology*, AMS, 6-12 August, 2003, Seattle, WA, 960-963.

Brown, R. A., V. Wood, B. Flickinger, and E. Forren, 2003: Experimental high-resolution WSR-88D measurements in tornadic storms. *Program Volume, Nat. Weather Assoc. Annual Meeting*, Jacksonville, FL, 61.

Brown, R. A., B. Flickinger, E. Forren, D. Schultz, P. Spencer, V. Wood, and C. Ziegler, 2004: Experimental high-resolution WSR-88D measurements in severe storms. *Preprint CD, 20th Conf. on Interactive Information Processing Systems for Meteor., Oceanography, and Hydrology*, Seattle, WA, Amer. Meteor. Soc., Paper 12.9.

Brown, R. A., B. A. Flickinger, E. Forren, D. M. Schultz, D. Sirmans, P. L. Spencer, V. T. Wood, and C. L. Ziegler, 2004: Improved detection of severe storms using experimental fine-resolution WSR-88D measurements. *Wea. Forecasting*, **19**, accepted.

Brown, R. A., R. M. Steadham, B. A. Flickinger, R. R. Lee, D. Sirmans, and V. T. Wood, 2005: New WSR-88D volume coverage pattern 12: Results of field tests. *Wea. Forecasting*, submitted.
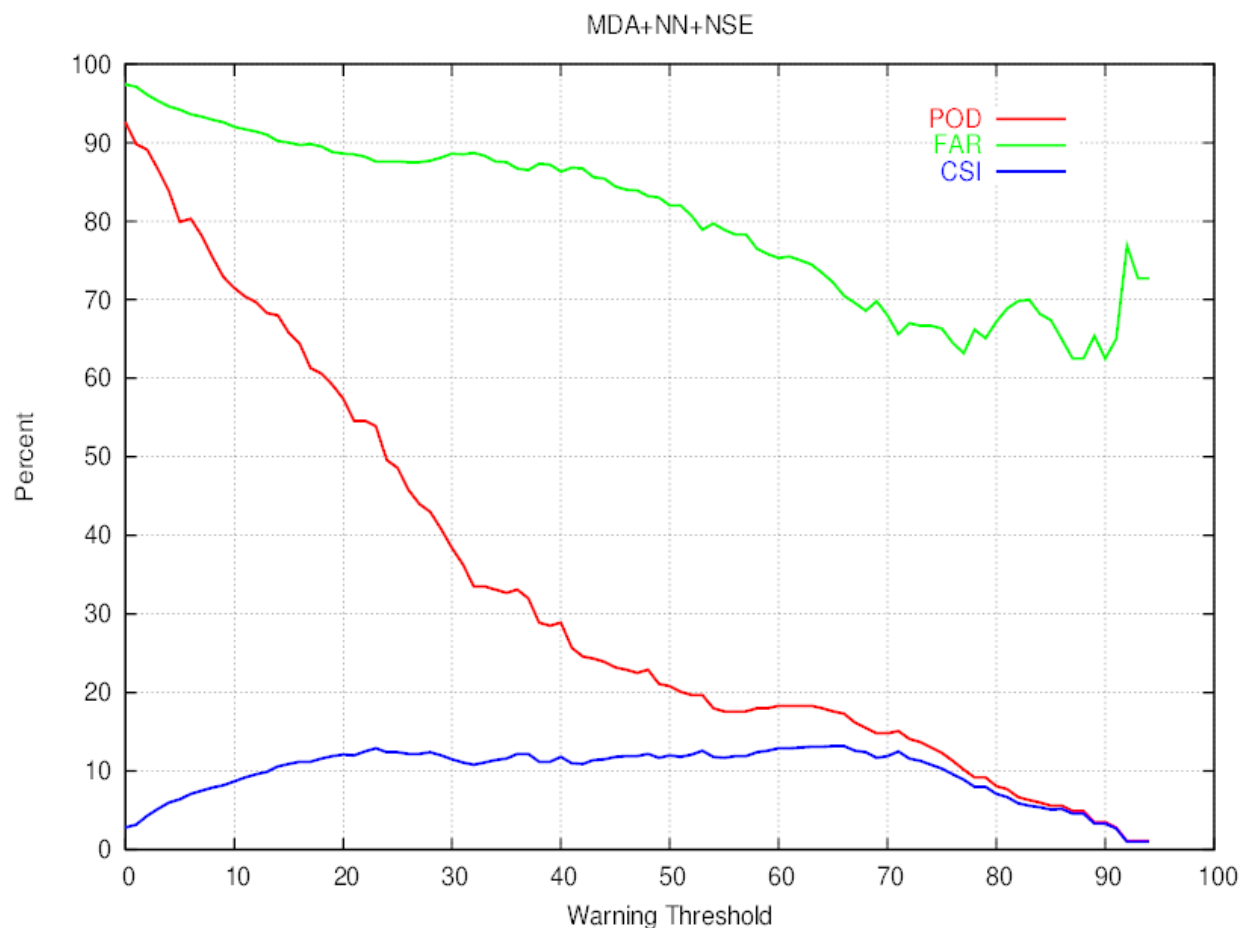
Skill scores (POD, FAR, and CSI) for MDA+NN+NSE tornado probabilities. Probabilities are expressed as Warning Threshold.

NSSL3: Severe Weather Warning Research and Application Development – *VCPExplorer*
Manross, **Smith**, **Stumpf**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Create a platform-independent tool for visualizing radar propagation path with respect to the terrain surrounding the radar; provide additional enhancements for forecaster training, such as display of non-standard beam propagation using point soundings, and display of radar algorithm output dependent on range from radar and volume coverage pattern (VCP).

Accomplishments
While some minor fixes and enhancements continue on the VCPExplorer, this highly interactive application was completed and provided to the WDTB in late spring 2004. It has already been used in the first round of WDTB's Advanced Warning and Operations Course (AWOC).
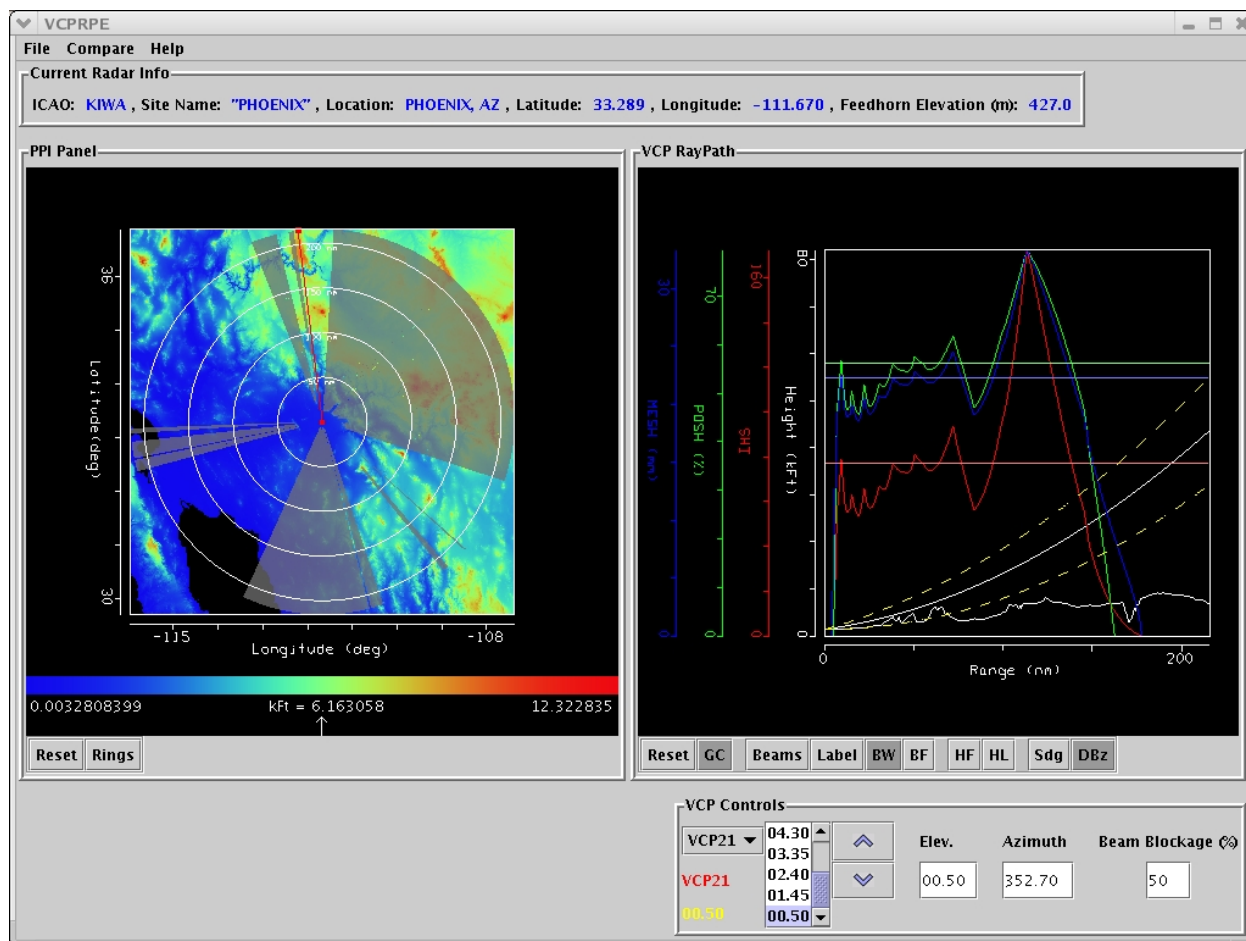
VCPExplorer with PPI (left panel), RHI (right panel), VCP Controls (bottom) and Location (top). In the figure, the colored background in the PPI panel represents terrain surrounding the KIWA (Phoenix, AZ) WSR-88D. Shaded regions are areas of ground clutter based 50% beam blockage at 0.5 degree beam elevation. The red line indicates radar beam location. The RHI panel displays standard "4/3 Earth Radius" beam path (white curve) with beam edges (yellow dashed). The jagged white line indicates terrain under the radar beam in PPI panel. Colored jagged lines are various algorithm output with respect to range, where horizontal lines of the same color indicate theoretical values.

NSSL5: Investigation of the Use of Dual-Polarization Radar to Improve Quantitative Precipitation Estimation for Improving Flash Flood and Flood Detection, Warnings, and Forecasts – *Joint Polarization Experiment (JPOLE)*
Schuur, Ryzhkov, Heinselman, Melnikov, Scharfenberg, Burgess, Krause

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Complete data analyses and produce reports to demonstrate the utility of a polarimetric WSR-88D and support a decision briefing to the NEXRAD Program Management Committee (NPMC) on upgrading the national network of WSR-88D's to include polarimetric capabilities.

Accomplishments
The Joint Polarization Experiment (JPOLE), conducted from the spring 2002 through spring 2003, was designed to test the polarimetric WSR-88D (hereafter referred to as KOUN) radar engineering design, evaluate radar data quality, demonstrate utility and feasibility to operational users, and collect data and information that could be used to perform a cost/benefit analysis. Analyses of JPOLE data in support of a

decision briefing to the NEXRAD Program Management Committee (NPMC) culminated in the fall of 2003 with the writing of several reports that evaluated the operational capabilities of the KOUN radar.

Overall, KOUN was found to routinely produce polarimetric measurements of exceptional quality. The KOUN data archive from JPOLE contains an unprecedented collection of 98 meteorological and nonmeteorological events (example from 10 May 2003 shown below). Using this dataset, analyses were conducted to demonstrate KOUN's ability to provide improved quantitative precipitation estimates, discriminate between hydrometeor types, and eliminate nonmeteorological artifacts. Rainfall estimation was found to be dramatically improved in terms of both bias and RMS error while classification algorithms demonstrated great skill at pinpointing the location of hail within storms, discriminating between snow and rain, identifying the location of strong tornadoes, and improving data quality. The utility of polarimetric data to operational forecasters was also examined during JPOLE. A KOUN scanning strategy was designed to emulate the elevation angles, scanning rates, and volume coverage times used by standard WSR-88D radars. Real-time polarimetric data and outputs were supplied to forecasters at the Norman NWS forecast office (with NSSL observers assisting the forecasters in the analysis and interpretation of the polarimetric radar data and outputs during an intense three month data collection period in spring 2003). In several instances, KOUN data and outputs proved to provide value-added information to the warning decision process.

As a result of this work, the NPMC in fall 2003 approved taking the first steps toward upgrading the operational WSR-88D network to include polarimetric capabilities. This NPMC decision represents a significant milestone in the continuing evolution of the WSR-88D radar network.

Publications

Ryzhkov, A., S. Giangrande, and T. Schuur, 2003: Rainfall measurements with the polarimetric WSR-88D radar. Report of the National Severe Storms Laboratory, Norman, OK, 73069, 98 pp.

Ryzhkov, A. V., T. J. Schuur, D. W. Burgess, S. Giangrande, and D. S. Zrnic, 2004: The Joint Polarization Experiment: Polarimetric rainfall measurements and hydrometeor classification. *Bull. Amer. Meteor. Soc.*, submitted.

Scharfenberg, K.A., D.J. Miller, P. Heinselman, D.L. Andra, Jr., and M.P. Foster, 2004: Highlights from the Joint Polarization Experiment operational demonstration. *Preprints, 20th Conf. on Weather Analysis and Forecasting*, Seattle, WA, Amer. Meteor. Soc., CD-ROM, 10.5.

Schuur, T., P. Heinselman, K. Scharfenberg, A. Ryzhkov, D. Zrnic, V. Melnikov, and J. Krause, 2003: Overview of the Joint Polarization Experiment (JPOLE). Report of the National Severe Storms Laboratory, Norman, OK, 73069, 39 pp.

Schuur, T., A. Ryzhkov, P. Heinselman, D. Zrnic, D. Burgess, and K. Scharfenberg, 2003: Observations and classification of echoes with the polarimetric WSR-88D radar. Report of the National Severe Storms Laboratory, Norman, OK, 73069, 46 pp.

Schuur, T. J., A. V. Ryzhkov, P. L. Heinselman, D. W. Burgess, and K. A. Scharfenberg, 2004: The Joint Polarization Experiment: A summary of dual-polarization WSR-88D radar data collection and analysis, *Preprints, 20th International Conference on Interactive Information and Processing Systems (IIPS)*, Seattle, WA, Amer. Meteor. Soc., Boston, CD-ROM, 12.1.
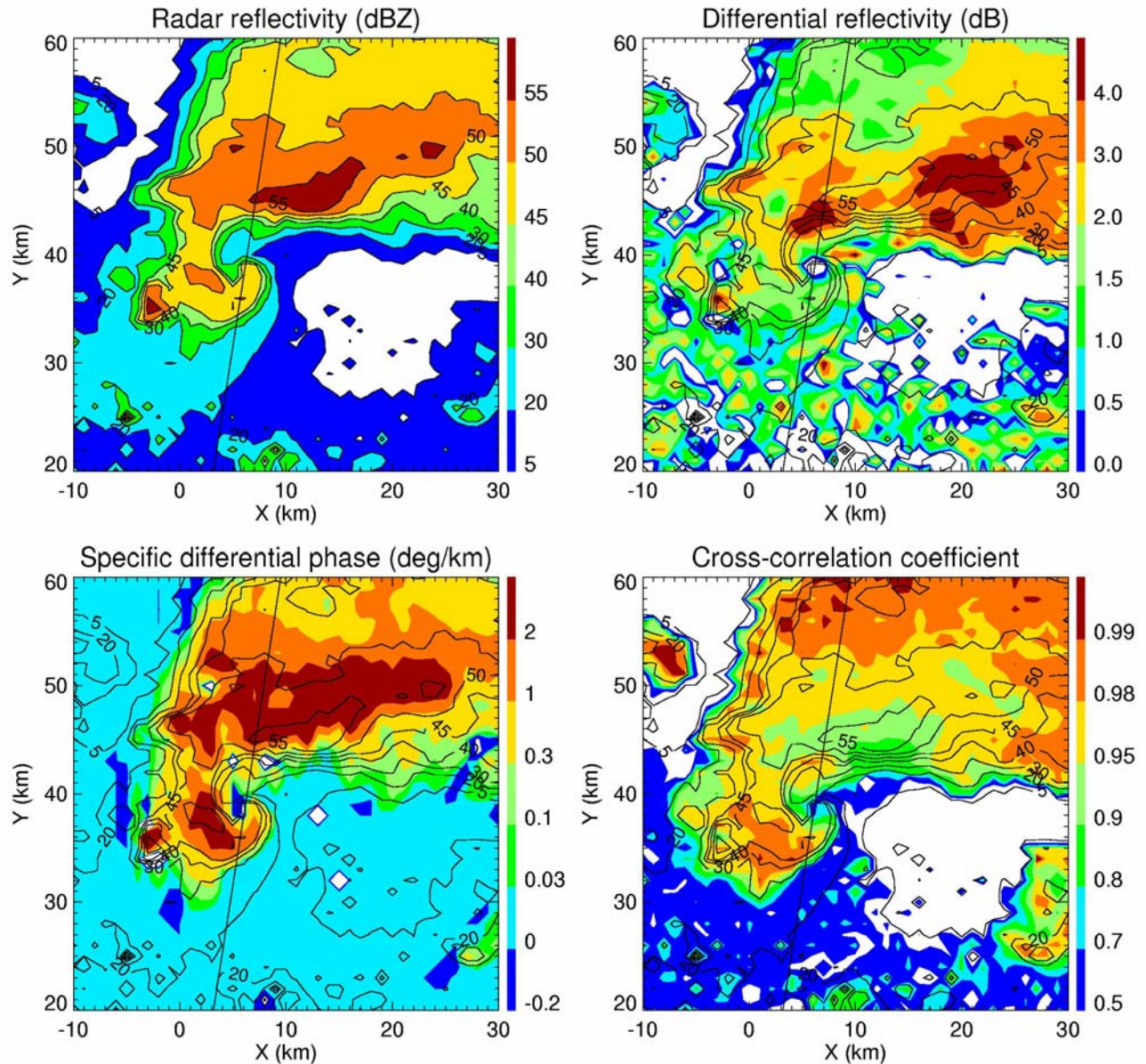
Fields of radar reflectivity (Z), differential reflectivity (Z_{DR}), specific differential phase (K_{DP}), and cross-correlation coefficient (ρ_{HV}) at 0346 UTC on 10 May 2003.

NSSL5: Investigation of the Use of Dual-Polarization Radar to Improve Quantitative Precipitation Estimation for Improving Flash Flood and Flood Detection, Warnings, and Forecasts – *Dual-Polarization Radar Research*
Ryzhkov, Schuur, Heinselman, P. Zhang, Melnikov, Giangrande, Krause

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Create new algorithms that exploit the expanded capabilities of dual-polarization radar; develop techniques to provide improved data quality for the prototype polarimetric KOUN WSR-88D radar.

Accomplishments

In the past year, work continued to collect and analyze data from the prototype polarimetric KOUN WSR-88D radar and to develop algorithms that discriminate between meteorological and non-meteorological echoes, identify hydrometeor types, and improve rainfall estimation.

In investigations of polarimetric classification techniques, polarimetric radars were shown to be capable of tornado detection through the recognition of tornadic debris signatures characterized by anomalously low cross-correlation coefficient ρ_{hv} and differential reflectivity Z_{DR}. This capability was demonstrated for three significant tornadic storms that struck the Oklahoma City metropolitan area. The first tornadic debris signature, based on the measurements with the National Severe Storms Laboratory's Cimarron polarimetric radar, was reported for a storm on 3 May 1999. Similar signatures were identified for two significant tornadic events during the Joint Polarization Experiment (JPOLE) in May 2003. The data from these storms were collected with a polarimetric prototype of the NEXRAD radar. In addition to a small-scale debris signature, larger-scale polarimetric signatures that might be relevant to tornadogenesis were also persistently observed in tornadic supercells. The latter signatures are likely associated with lofted light debris (leaves, grass, etc.) in the inflow region and intense size sorting of hydrometeors in the presence of strong wind shear and circulation. Analyses of data sets from the 2003 season were also used to refine polarimetric hail classification techniques. Using in-situ hail observations from the 2003 JPOLE project as a verification dataset, the polarimetric Hail Classification Algorithm was tuned to provide hail identification that had a higher Probability of Detection (POD), and lower Probability of False Detection (POFD) and False Alarm Rate (FAR) than that provided by the conventional Hail Detection Algorithm. Preliminary work also began to develop a polarimetric hail sizing algorithm.

The capability of the KOUN radar to provide improved rainfall estimates was investigated. A large dataset from the Agricultural Research Services (ARS) micronet of rain gauges was used to validate different polarimetric algorithms for rainfall estimation (see figure below). One-hour rain totals were estimated from the KOUN radar using conventional and polarimetric algorithms and compared with hourly accumulations measured by the gauges. Both point and areal estimates were examined. The use of a new "synthetic" polarimetric rainfall estimation algorithm resulted in a significant reduction in the RMS errors of hourly rain estimates (when compared to results from the conventional algorithm): 1.7 times for point measurements and 3.7 times for areal rainfall measurements. A novel technique to identify the radar bright band was also developed. Work on the bright band detection algorithm will continue into the coming year with output from the algorithm being used to refine rainfall estimation in areas of bright band contamination and to provide information that can be used to provide more accurate hydrometeor type classification in winter storms.

Techniques for absolute calibration of radar reflectivity Z and differential reflectivity Z_{DR} measured with dual-polarization weather radars were also examined. Calibration of Z was based on the idea of self-consistency among Z, Z_{DR}, and specific differential phase K_{DP} in rain. The proposed scheme substantially reduces the impact of variability in drop size distribution and raindrop shape on the quality of Z calibration. The new calibration technique was tested on a large polarimetric dataset obtained during JPOLE, yielding an accuracy of Z calibration within 1 dB. Absolute calibration of Z_{DR} was performed using solar measurements at orthogonal polarizations and polarimetric properties of natural targets like light rain and dry aggregated snow that are probed at high elevation angles. Because vertical sounding is prohibited for operational WSR-88D radars due to mechanical constraints, the existing methodology for Z_{DR} calibration was modified for non-zenith elevation angles. It was shown that the required 0.1 – 0.2 dB accuracy of Z_{DR} calibration is potentially achievable.

Publications

Giangrande, S. E., and A. V. Ryzhkov, 2004: Calibration of dual-polarization radar in the presence of partial beam blockage, *J. Atmos. Oceanic Tech.*, submitted.

Ryzhkov A.V. and S. Giangrande, 2004: Measurements of rain with a polarimetric WSR-88D radar: Operational demonstration. *Preprint CD, 6th International Symposium on Hydrological Applications of Weather Radar*. Melbourne, Australia, 8 pp.

Ryzhkov, A. V., S. E. Giangrande, V. M. Melnikov, and T. J. Schuur, 2004: Calibration issues of dual-polarization radar measurements, *J. Atmos. Oceanic Tech.*, submitted.

Ryzhkov, A. V., S. E. Giangrande, and T. J. Schuur, 2004: Rainfall estimation with a polarimetric prototype of the WSR-88D radar, *J. Appl. Meteor.*, submitted.

Ryzhkov, A. V., T. J. Schuur, D. W. Burgess, and D. S. Zrnic, 2004: Polarimetric tornado detection, *J. Appl. Meteor.*, in press.

Zrnic, D.S. and A.V. Ryzhkov, 2004: Polarimetric properties of chaff. *J. Atmos. Oceanic Tech.*, **21**, 1017 - 1024.
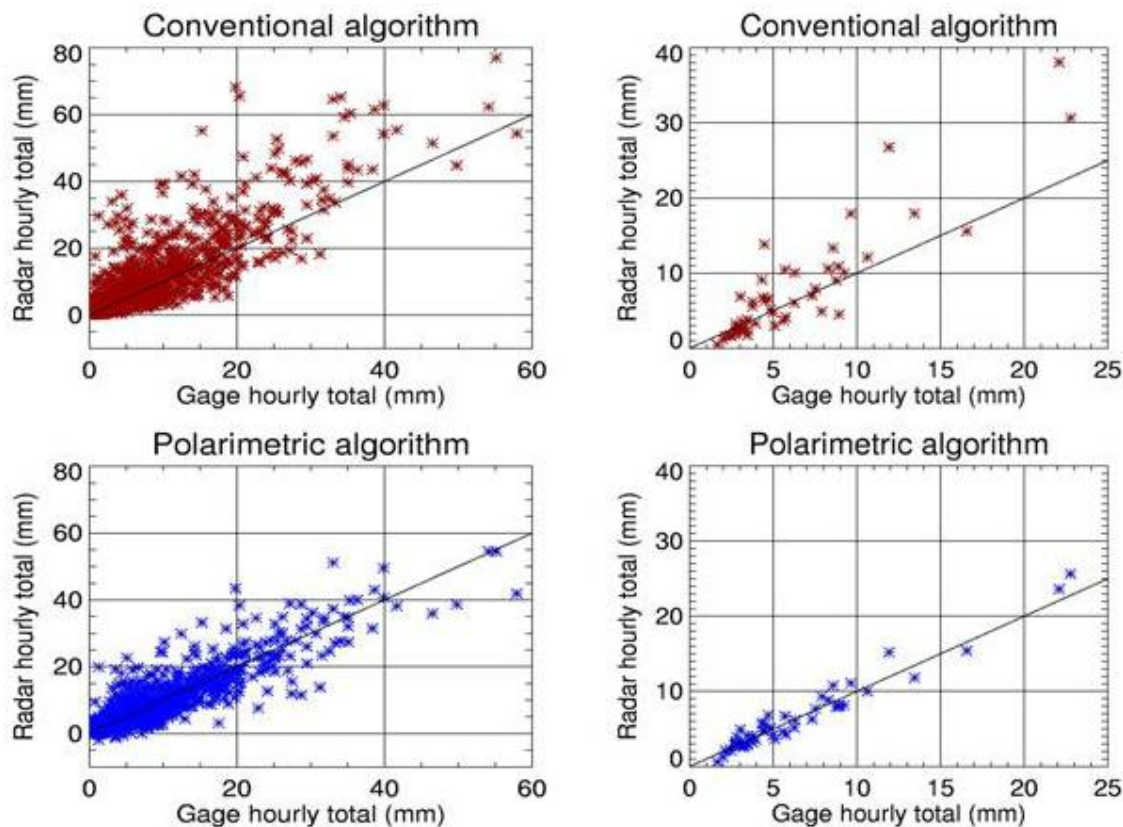
One-hour individual gage (left column) and watershed areal (right column) rainfall accumulation comparison with estimates from conventional R(Z) and polarimetric R(Z,Z$_{DR}$,K$_{DP}$) algorithms. Rain gage data is from the 42 station USDA Agricultural Research Service micronet, which has an average gage spacing of approximately 5 km. Data presented represents 50 hours of observations.

NSSL7: Investigation of Advancements in Radar Technology toward the Improvement of Hazardous Weather Detection and Warnings – *Mitigation of Range and Velocity Ambiguities*
Torres, Sachidananda

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Mitigation of range and velocity ambiguities in WSR-88D data.

Accomplishments
In the WSR-88D, the range and Doppler velocity ambiguity problems are coupled such that trying to alleviate one of them worsens the other. Special techniques are necessary to resolve both ambiguities to the levels required for the efficient observation of severe weather. Efforts in this area are expected to culminate in significantly improved WSR-88D data quality when implemented on the Open Radar Data Acquisition (RDA) sub-system. The increased data quality will result in an improved ability for the WSR-88D to detect severe weather, flash floods, winter storms, and provide aviation forecasts.

Over the last decade, two techniques have emerged as viable candidates to address the mitigation of range and velocity ambiguities in the WSR-88D, thus reducing the amount of purple haze obscuration currently encountered during the observation of severe phenomena. These are systematic phase coding

and staggered pulse repetition time (PRT). The two techniques are complementary since they offer advantages at specific elevation angles; hence, they can be simultaneously incorporated into the same volume coverage pattern (VCP).

In conjunction with NCAR, we have recently recommended to the ROC an algorithm for the initial deployment of range and velocity ambiguity mitigation techniques on the RDA subsystem. The algorithm, referred to as SZ-2, is based on systematic phase coding that uses the SZ(8/64) code and will replace the Doppler half of split cuts at the lowest elevation angles of the antenna beam.

Research continued for the staggered PRT method. The algorithm was refined and tested on data collected with the KOUN radar. At the core of this technique is a new velocity dealiasing function that extends the maximum unambiguous Doppler velocity by efficiently combining velocity estimates from two PRTs. In addition, a novel staggered PRT ground clutter filter was developed. This filter achieves suppression levels at those required in an operational environment.

Publications

Torres, S. M., Y. Dubel, and D. S. Zrnic, 2004: Design, implementation, and demonstration of a staggered PRT algorithm for the WSR-88D. *J. Atmos. Oceanic Technol.*, **21**, 1389-1399.

Torres, S., and D. Zrnic, 2004: Range and velocity ambiguity mitigation techniques for the WSR-88D weather radar. *Preprints, International Geoscience and Remote Sensing Symposium 2004*, Anchorage, AK, Inst. of Electrical and Electronics Engineers.

Torres, S., 2003: Processing of staggered PRT sequences on the KOUN research radar. *Preprints, 31st International Conference on Radar Meteorology*, Seattle, WA, Amer. Meteor. Soc., 746-748.
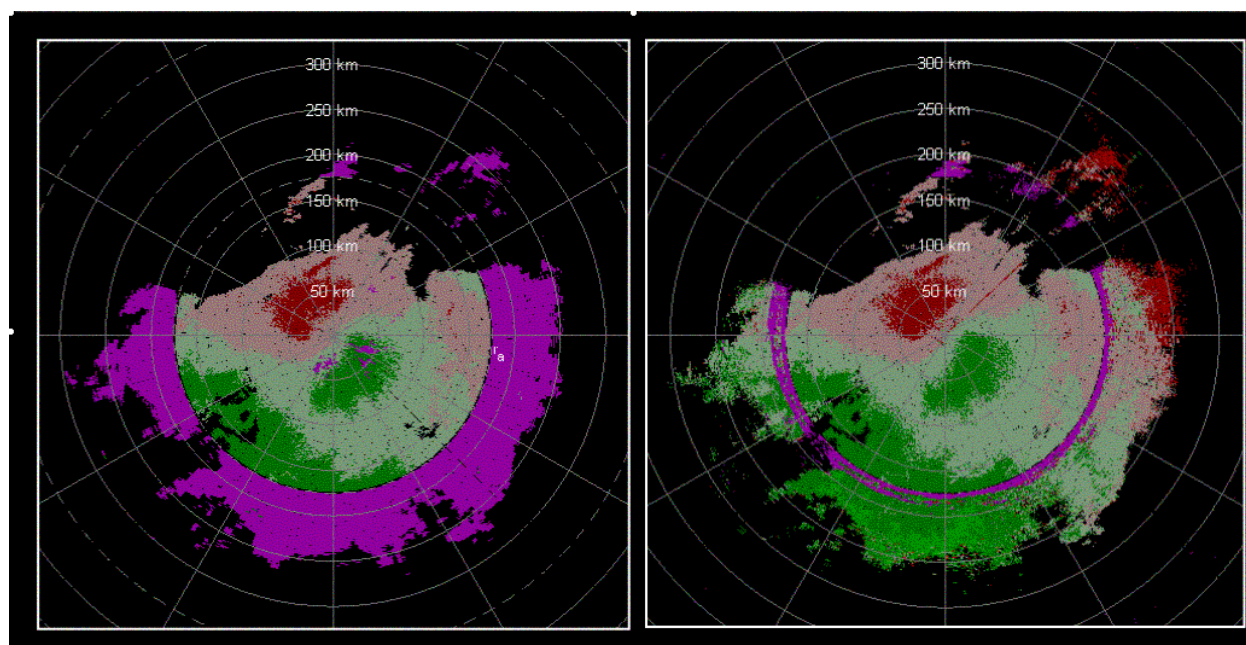
Range-velocity ambiguities on the current WSR-88D (left) and using the recommended SZ-2 algorithm (right), from data collected with KOUN on 10/08/02 at 1511 GMT. Note the dramatic improvement (i.e., reduction of purple haze) obtained with the SZ-2 algorithm.

NSSL7: Investigation of Advancements in Radar Technology toward the Improvement of Hazardous Weather Detection and Warnings – *Improvement of Spectral Moment and Polarimetric Variable Estimates using a Pseudowhitening Transformation on Oversampled Range Data*

Torres, **Curtis**, **Ivic**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Improve Doppler spectral moment and polarimetric variable estimates through use of a pseudowhitening transformation on oversampled range data.

Accomplishments
Range oversampling followed by a pseudowhitening transformation is a novel method for increasing the number of independent samples from which to estimate the Doppler spectrum, its moments, as well as several polarimetric variables on pulsed weather radars. Since errors of estimates increase with increased antenna rotation speed, the decreased errors associated with pseudowhitening permit the antenna to rotate faster while maintaining the current errors of estimates. It follows that storms can be surveyed much faster than is possible with current processing methods. Alternatively, for a given volume scanning time, errors of estimates can be greatly reduced. These are important considerations in WSR-88D operations. This technique can be advantageously exploited in a combination of faster data temporal acquisition and denser spatial sampling as needed to satisfy some of the evolutionary requirements for the WSR-88D.

Pseudowhitening techniques were developed as practical solutions that achieve an optimal compromise between variance reduction and noise sensitivity. Based on regularization methods for the solution of ill-conditioned problems, two pseudowhitening schemes were proposed: the clipped-singular-value-decomposition transformation and the sharpening filter. Estimators based on pseudowhitening techniques avoid the pitfalls of their whitening-transformation-based counterparts and lead to more accurate radar products and/or rapid data acquisition for a much wider range of signal-to-noise ratios.

To test the aforementioned pseudowhitening techniques on real data, time series data acquired at sampling rates higher than usual were collected and processed offline. To achieve this, the NSSL KOUN radar was equipped with a digital receiver capable of producing samples at the desired data rate. Also, a disk array capable of storing data at rates of up to 80 MB s^{-1} was added to the system. This combination allows for recording of time series data with oversampling factors of 5 in dual polarization mode and 10 in single polarization mode, making KOUN the only WSR-88D in the world capable of acquiring and recording unlimited oversampled, dual-polarization time series data.

Publications
Torres, S. M., C. D. Curtis, and J. R. Cruz, 2004: Pseudowhitening of weather radar signals to improve spectral moment and polarimetric variable estimates at low signal-to-noise ratios. *IEEE Trans. Geosci. Remote Sensing*, **42**, 941-949.
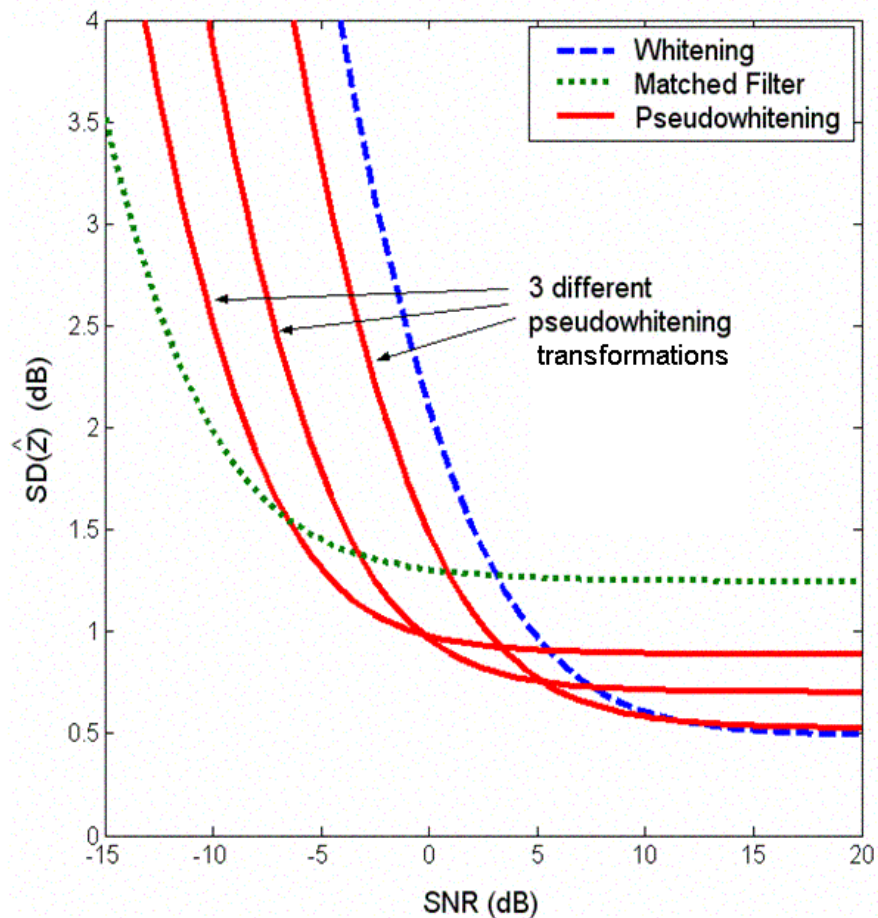
Standard error of reflectivity estimates versus the signal-to-noise ratio (SNR). The green curve corresponds to the current performance of the WSR-88D that uses a matched-filter receiver. The blue curve shows the performance of a whitening transformation that achieves the smallest errors at large SNRs but exhibits undesirable large errors at intermediate to low SNRs. The red curves show the performance of three different pseudowhitening transformations. By varying the pseudowhitening parameter, it is possible to control the trade-off between variance reduction at large SNRs and the level of errors at low SNRs.

NSSL7: Investigation of Advancements in Radar Technology toward Improvement of Hazardous Weather Detection and Warnings – *Shared Mobile Atmospheric Research and Teaching Radar (SMART- R)*
Biggerstaff, **Wicker**, Texas Tech and Texas A&M collaborators

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Study convective and mesoscale atmospheric processes to help improve forecasts of significant weather events such as flash floods, hurricanes, and tornadoes.

Accomplishments
The Shared Mobile Atmospheric Research and Teaching Radar (SMART-R) had an active fiscal year deployment schedule. First, in September 2003, and for the first time, two mobile C-band Doppler radars were deployed to gather data to study boundary layer roll structures as well as the processes leading to tremendous inland rainfall and flooding during a landfalling hurricane. This deployment was a

collaborative effort between Dr. John Schroeder (Texas Tech) and Dr. Mike Biggerstaff (OU). Both radars were located in southeast North Carolina to study Hurricane Isabel's landfall near the Outer Banks. Data were collected for nearly 36 hours as the storm came ashore as a Category 2 hurricane (see first figure below). Data from this event is being studied by Texas Tech.

The SMART radars were used for educational purposes by Dr. Biggerstaff during spring 2004 in his Radar Meteorology class. Several dozen students took advantage of the facility to learn how to deploy and run the Doppler radar during special evening lab sessions. Many students felt that this type of "hands-on" experience was an important part of their education.

Both SMART radars were used in the Thunderstorm Electrification and Lightning EXperiment (TELEX) during May and June 2004. This program, led by Drs. Dave Rust (NSSL) and Don MacGorman (NSSL), focused on the generation of in-cloud and cloud-to-ground lightning within central Oklahoma thunderstorms. Dr. Biggerstaff led the SMART radar team effort to gather data that provided the kinematic framework from the thunderstorms. Several important data sets were collected, including a several hour, dual-Doppler data set from the 29 May Geary, OK, tornadic supercell that was responsible for a long swath of damage from west-central Oklahoma into the northwestern portion of the Oklahoma City metropolitan area (see second figure below). This data set is one of the longest high frequency data sets ever collected from a thunderstorm, and provides an unprecedented opportunity to study the storm's kinematics and electrical structures.
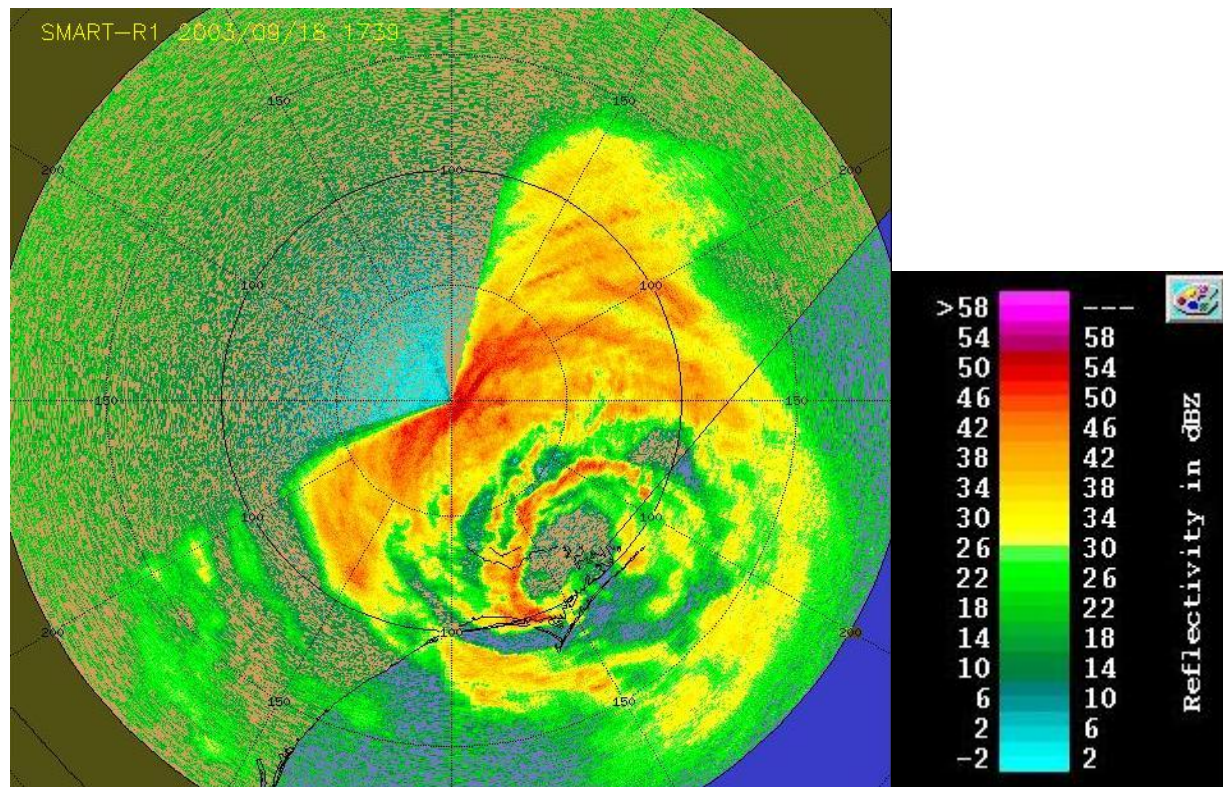
Base radar reflectivity from 17 September 2003 at 1739 UTC from SR-1. Hurricane Isabel is landfalling along the North Carolina coast at this time. Multiple eyewall structures are apparent, as well as asymmetries in the storm structure. The beam blockage northeast of the radar is due to trees and hills.

Mercator
Scale 1:1000000

36.3N
99.1W

SMART-R2

35.4N
97.5W

-10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

SMART-R2 at 35 29 51 N 98 27 55 W, 490.0 m.
Volume = 2004/05/30 00:30:39. Sweep 2004/05/30 00:30:57, angle = 1.7°
Data type: DB_CDBZ (Corrected reflectivity (1 byte))
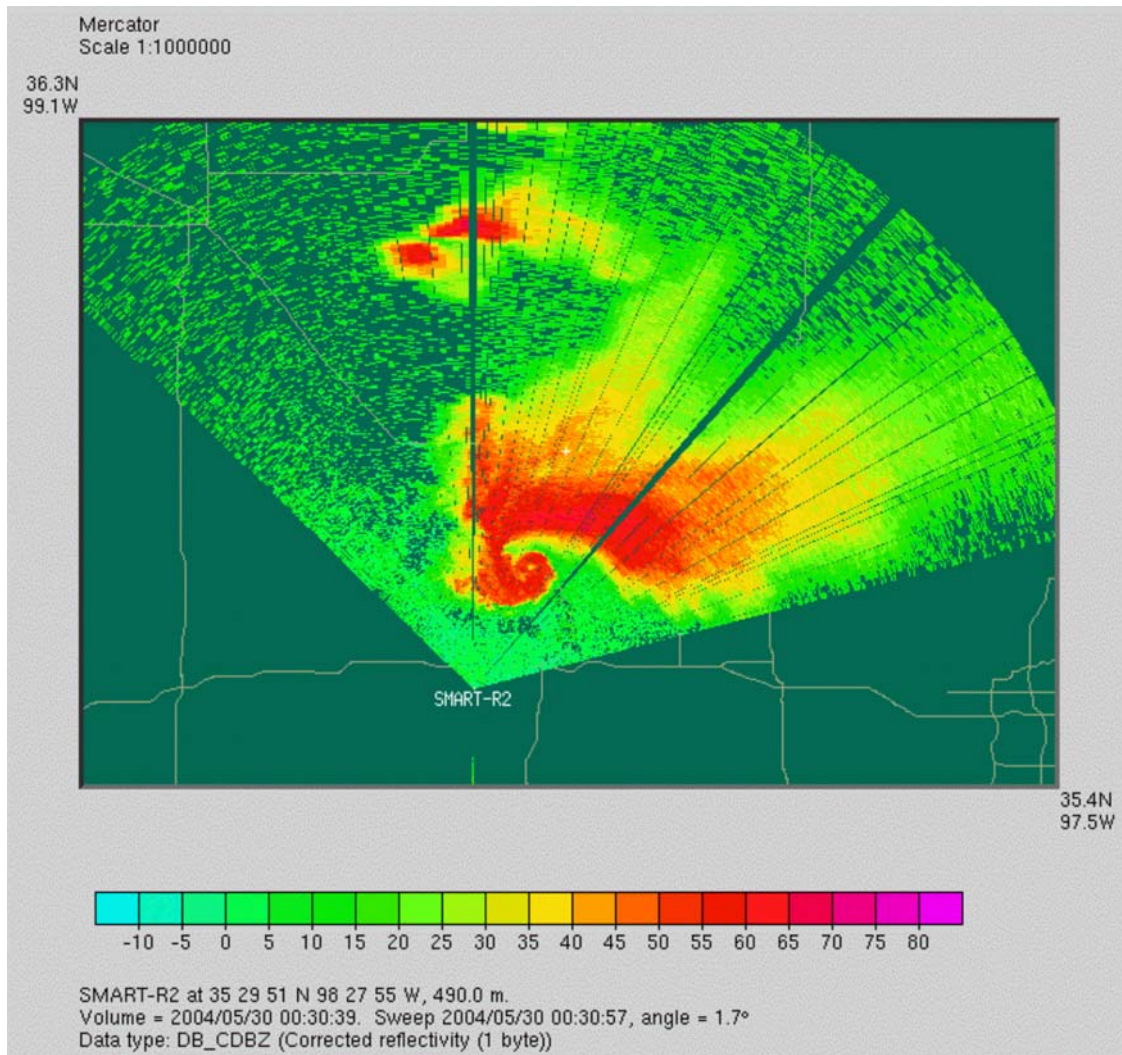
Supercell thunderstorm with hook echo and tornadic "doughnut hole" from the 29 May supercell (0030 UTC on 5/30) in west-central Oklahoma. Reflectivity at 1.7 degrees elevation is shown. The storm is roughly 20 km north of the radar and 20 km west of Oklahoma City.

NSSL7: Investigation of Advancements in Radar Technology toward the Improvement of Hazardous Weather Detection and Warnings – *Research Radar Analysis Tool*
Priegnitz, Jain

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Provide visual feedback of time series spectra at selected gates to traditional moment displays (i.e., PPI views); link the time series data and moment data together to improve identification of meteorological and non-meteorological targets in time series data.

Accomplishments
The Research Radar Analysis Tool (RRAT) was developed to support analysis of time series radar data collected by the KOUN radar. The RRAT has been used by researches at OU to look for tornadic

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signatures in the time series. It was also used by a graduate student to look for non-meteorological targets such as aircraft and birds.

Publications
Priegnitz, D.L., and M. Jain, 2004: The Research Radar Data Analysis Tool (RRAT). *Preprints, 20th International Conference on Interactive Information Processing Systems (IIPS)*, Seattle, WA, Amer. Meteor. Soc., CD-ROM, P1.5.
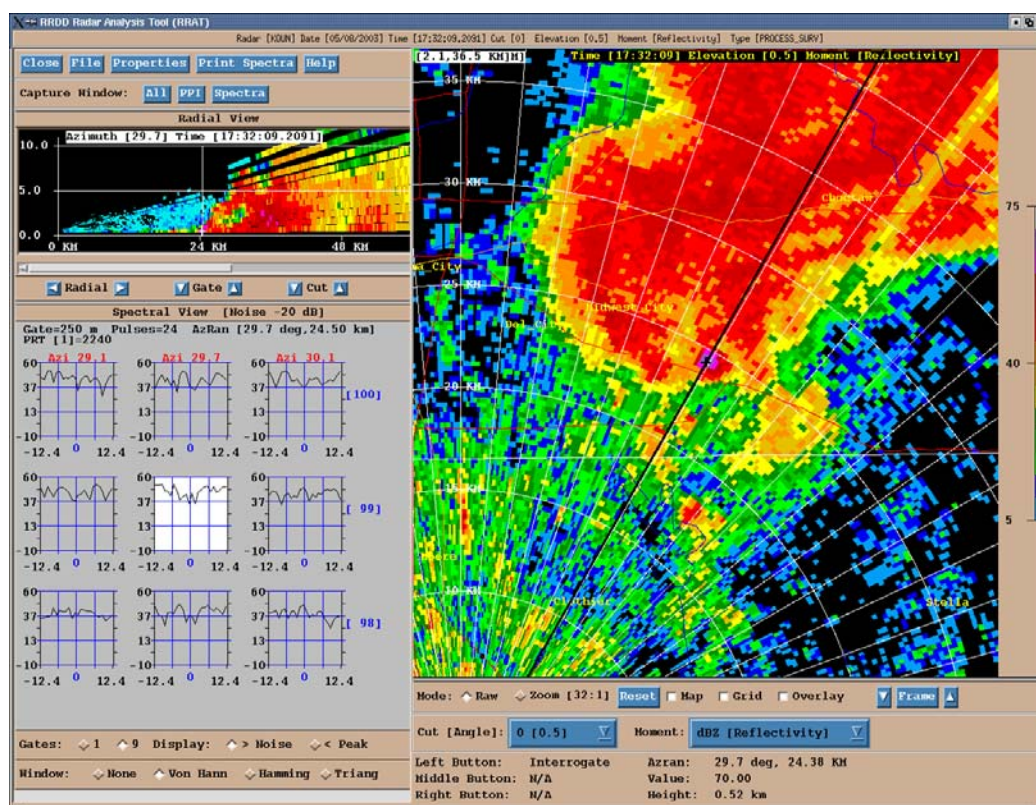
Sample RRAT display of reflectivity and time series spectra data for a tornadic storm on 8 May 2003. The selected gate is at the location of tornadic debris and is denoted by a "+" in the reflectivity display.

NSSL7: Investigation of Advancements in Radar Technology toward the Improvement of Hazardous Weather Detection and Warnings – *Super Resolution Radar Data*
Brown, **Curtis, Forren,** Jain

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Assess the operational benefit as well as the engineering/performance impact of implementing "super resolution" (0.5 degree azimuthal resolution and 0.25 km reflectivity range resolution) base data on the WSR-88D network.

Accomplishments
The current WSR-88D network generates base data at a radial resolution of one degree azimuth and reflectivity data at a range resolution of one km. NSSL has been tasked by the NWS to assess the operational benefit as well as the engineering/performance impact of implementing "super resolution" (0.5 degree azimuthal resolution and 0.25 km reflectivity range resolution) base data on the WSR-88D network. Analyses of super resolution base data have been performed and show the most significant benefits are gained from the increased azimuthal resolution. In particular, when data are collected and

processed at 0.5 degree azimuthal intervals (reducing the effective azimuthal beam width), a given circulation can be detected 1.5 times further (50 percent increase) in range than for the legacy one degree sampling.

Engineering analyses have also been performed to investigate the best methods of implementing the super resolution data and identifying issues and tradeoffs. A significant challenge is balancing the scientific and operational gains with the constraints imposed by the existing system and compatibility issues associated with other future scientific implementations on the WSR-88 system. This work is ongoing.

NSSL7: Investigation of Advancements in Radar Technology toward the Improvement of Hazardous Weather Detection and Warnings – *Radar Data Quality for the Korean Meteorological Administration*
Burcham, Jain, **J. Zhang**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Evaluate radar data quality issues of Korean Meteorological Administration (KMA) radars and identify solutions to improve their radar data quality.

Accomplishments
In collaboration with KMA scientists, NSSL and CIMMS scientists have evaluated KMA datasets for data quality issues. Primary issues are centered on residual ground clutter, anomalous propagation, sea clutter, sun strobes, point targets, and velocity dealiasing. Existing radar data quality algorithms have been identified that are expected to mitigate the identified problems. Work has progressed in integrating these algorithms into a system that can easily process the KMA datastreams. Evaluation of the algorithms' performance is ongoing.

NSSL8: Investigation into the use of Phased Array Radar Technology for Improving Hazardous Weather Detection and Warnings – *National Weather Radar Testbed*
Adams, Benner, Burcham, Curtis, Forsyth, Hondl, Jain, **Priegnitz, Staples, Suppes, Thompson,** Zahrai, **Zrnic**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Prepare the National Weather Radar Testbed (NWRT) Phased Array Radar (PAR) for scientific and engineering evaluation; perform engineering analyses of PAR data to identify and assess data quality issues associated with the new system; use these analyses to prioritize and resolve identified issues; and begin meteorological analyses of PAR data to evaluate the utility of using PAR technology for meteorological purposes

Accomplishments
The NWRT prototype system was delivered from Lockheed-Martin in late 2003. Efforts to date have primarily concentrated on engineering studies of the system. These studies have been aimed at understanding the system and addressing deficiencies. Work has included designing new scan strategies, data collection, engineering analysis of the data, configuration control of the delivered software and hardware, identification and repairing of software defects, and improving the functionality of the system. Collaborative work between NSSL, CIMMS/OU, Lockheed-Martin, the Federal Aviation Administration, and Basic Commerce Industries staff have led to the resolution of data quality and operational issues identified in the new system. Work continues to improve the data quality and usability of the NWRT so that it can become a one-of-a-kind research tool.

Data for meteorological analysis were collected during the reporting period. In particular, a data set of time series and moment data were collected from a tornadic event on 29-30 May 2004 in west-central Oklahoma. Evaluation and comparison of these data with simultaneously collected WSR-88D data at the KTLX east of Oklahoma City is ongoing. Example images of NWRT and WSR-88D KTLX data for this storm are shown in the figure below.
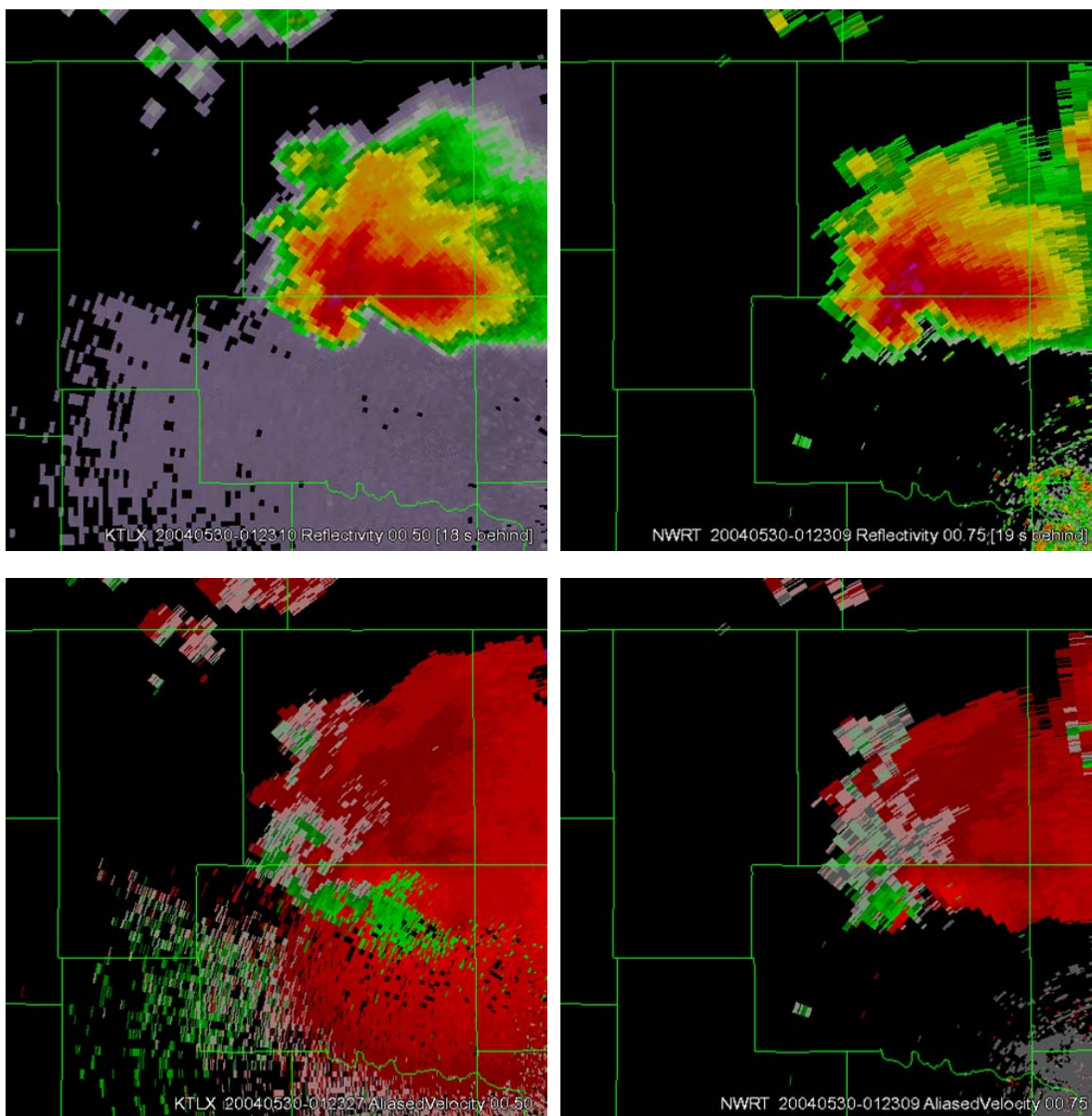
Images of NWRT and KTLX WSR-88D radar data for a tornadic event on 29-30 May, 2004: (upper left) KTLX reflectivity from 01:23:10 UTC at 0.5 deg.; (upper right) NWRT reflectivity from 01:23:09 UTC at 0.75 deg.; (lower left) KTLX velocity from 01:23:27 UTC at 0.5 deg.; (lower right) NWRT velocity from 01:23:09 UTC at 0.75 deg.

NSSL8: Investigation into the use of Phased Array Radar Technology for Improving Hazardous Weather Detection and Warnings – *Engineering Studies*
Crain, Havlicek, **Yu**, **Yeary**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Develop and install hardware and software to allow for continuous rotation of the antenna.

Accomplishments
After the initial configuration of the antenna was installed, a number of problems with the radar excitation and signal processing have been identified and most resolved. One such issue involves continuous rotation of the antenna. The initial configuration allowed only 720 degrees of rotation before it was necessary to unwind. This rotation capability was established in September.

Publications
Forsyth, D., et al., 2003: Building the National Weather Radar Testbed (Phased Array); *Preprints, 19th International Conference on IIPS*, Long Beach, CA; American Meteorological Society; 13-17 Jan 2003, 140-142.

NSSL8: Investigation into the use of Phased Array Radar Technology for Improving Hazardous Weather Detection and Warnings – *Radar Scheduler*
Priegnitz

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Improve the Radar Scheduler component of the NWRT, the primary user interface.

Accomplishments
Considerable work was done to modify the Radar Scheduler graphical user interface to improve feedback to the phased array radar user. Control and status objects were reorganized and color coded where needed to provide a better visual feedback to the operator. Error logging has been improved significantly by replacing cryptic error codes with descriptive text. Error messages have been time tagged to significantly improve trouble shooting in the event system errors occur during operations. Work has begun to improve feedback when running the system's Operational Readiness Tests (ORTS).

The Scenario Operation window is the window an NWRT operator will most likely be using during normal operations. Most status items are color-coded as red, yellow, green or white. Red is used to flag status items that need immediate attention or action items (i.e., buttons), and should be used with extreme caution. Yellow is used to flag status items that are in a "non-normal" state or action items that affect system operation. White is used to display information without determining significance (i.e., antenna rotation rate or position). Text strings displaying the latest Real-Time Controller (RTC) and Environmental Processor (EP) errors are displayed near the bottom of the window.

ROC: Analysis of Weather Radar Observations of Severe Convection to Understand Severe Storm Processes and Improve Warning Decision Support – *Algorithm Evaluation and Improvement, and Data Quality*
Wiegman, **Garfield**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Evaluate and improve WSR-88D algorithms and perform data quality assessments, with work accomplished by two OU graduate research assistants.

Accomplishments
Multiple Pulse Repetition Frequency Dealiasing Algorithm. The Radar Operation Center has recently fielded a range folding mitigation scheme for WSR-88Ds known as the Multiple Pulse Repetition Frequency Dealiasing Algorithm (MPDA) to reduce range folding (purple haze) in velocity products. Because areas that may be range folded using one Pulse Repetition Frequency (PRF) may not be range folded using another PRF, MPDA is designed to reduce range folding by combining the velocity data acquired using three different PRFs at the same elevation angle. In addition, the accuracy and the

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consistency of the velocity data collected can be checked against each other in areas where there is overlapping coverage. Two studies were conducted concerning the MPDA:

- The first study evaluated different methods for MPDA to determine output data bins of range folded data values. On the elevation angles that are processed by MPDA, up to three data values are obtained for each data bin. If one good velocity data value exists, the output data bin will contain good velocity data, otherwise, MPDA will determine if the output data bin should contain a range folded data value. The original method for determining a range folded data bin was if any two of the three data values collected contained range folded data values, and the third contained a missing data value or a range folded value, the output data bin was set to a range folded value. This technique was compared to a trial method on which the range folded data for a particular velocity field was used as a template, and velocity data from the other fields replaced as many range folded output data bins on the original field as possible. Analysis revealed not enough variation between the two methods existed to prompt a change in the algorithm.
- The second study evaluated range folding at elevations above those already processed by MPDA for an experimental Volume Coverage Pattern (VCP), VCP 45. VCP 45 is designed to have a more dense vertical sampling with a scanning strategy analogous to now operational VCP 12 fielded with Build 5, released in March 2004, and is designed to utilize MPDA for the lowest three elevations of the volume. Using several data cases, results indicated an additional elevation angle above those already processed by MPDA was needed. Therefore, VCP 45 was not ready for integration into the field.

Snow Accumulation Algorithm. Several tests with the user adaptable parameters of the Snow Accumulation Algorithm (SAA) were performed. A user is able to change the behavior of a meteorological algorithm by changing the user adaptable parameters. The first test performed was to verify the user adaptable parameters would not allow a user to enter values outside of the specified limits. With the limits of the user adaptable parameters validated, tests were performed to verify the products produced by SAA were logical by varying the user adaptable parameters. For example, if all of the user adaptable were set to produce the least amount of snow accumulation, the SAA products should return with little, if any, snow accumulation. While performing these tests, a problem was encountered with the Time Span Threshold, an adaptable parameter used to calculate snow accumulations during times of missing data and is not a parameter the field is allowed to adjust. It was found that errors occur when the Time Span Threshold is set to a value less than the time taken to complete a volume scan, and therefore, the Time Span Threshold was kept at its default value to complete the remaining tests. Results from the tests verify the product outputs by SAA are logical. Because the limits of the user adaptable parameters and the SAA products were verified, SAA will be integrated into Build 6 with deployment starting in September 2004.

Level II Data Quality. To support other projects, a data quality study was begun on Level II radar data archived by the National Climatic Data Center (NCDC). It has been observed that some of the archived radar data available contained blocks of missing data. A program, designed to analyze the data quality of archived radar data, was written as part of an investigation to determine the cause of the blocks of missing data. This program ingests and inspects the radar data for any discontinuities in the radar data. For each radar data file, the program outputs the Volume Coverage Pattern (VCP) used, whether or not volume header information was found, information about the block of missing data including size, and, if requested, information about each radial collected. This data quality analysis program is in use, and a second version of this program is in development which will allow the user more control over the information collected and output by the program.

Mesocyclone Detection Algorithm. During February-July 2004, contributions were made to the Independent Verification & Validation (IV&V) of the Mesocyclone Detection Algorithm (MDA). Tasks included assisting in the collection of radar data from severe thunderstorms to assess the performance of the MDA. Each tilt of the radar was organized into a spreadsheet to follow the progress of the individual MDA products through a volume scan. In so doing, it became possible to monitor the changes in each product to see if the algorithm was building them correctly.

ORDA. Participation also took place in the data quality assessment for the ORDA. In particular, work was done on the SIGMET/GMAP evaluation. Several spreadsheets were created that document the time, volume scan number, and VCP of the KTLX site to compare it with the same from KJIM (in essence, a calibration of KJIM using KTLX). In addition to this, tables were created that identify how many ".raw" and ".bz2" files correspond to a single volume scan.

ROC: Analysis of Weather Radar Observations of Severe Convective Storms to Understand Severe Storm Processes and Improve Warning Decision Support – *Best Use of Data by Forecasters*
Burgess

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Analyze data from the prototype ORDA and dual polarization radar systems to better understand how the data can best be used by forecasters; transfer the new understanding to operational forecasters before the installation of the new systems.

Accomplishments
Data from the KREX ORDA prototype were analyzed and compared to the baseline KTLX operational radar. Some problems with the data were discovered, pointed out to ROC personnel, and corrected. New ORDA capabilities were then documented. Additionally, initial steps were taken to prepare new ORDA training materials for Federal Meteorological Handbook # 11. Draft text was written and reviewed and draft radar image figures were determined.

Mobile, Dual-Doppler Analysis of Tornadogenesis: The 15 May 2003 Supercell in Shamrock, Texas
French, **Bluestein**, **Dowell**, **Wicker**, Kramar, Pazmany

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Perform a dual-Doppler radar intercept and analysis of a tornado-producing supercell.

Accomplishments
During the evening of 15 May 2003, a dual-Doppler dataset was collected, at a low elevation angle, through a supercell in the Texas Panhandle (near Shamrock) using the University of Massachusetts mobile, X-band radar and the SMART-R, mobile, C-band radar. The UMass radar also collected dual-polarization data. During the time data were collected, a tornado formed approximately 15 km (20 km) away from the U. Mass. (SMART-R) radar. Data collection began 20 minutes prior to tornadogenesis and continued through the lifetime of the tornado. This dataset allows a unique look at the wind field during tornadogenesis.

The ability to observe tornadogenesis, while rare and difficult to achieve, has been made easier in the last several years with the advancement of ground-based, mobile, Doppler radars. With the increase in the number of such radars, the opportunities for dual-Doppler analyses of tornadogenesis will increase, providing extremely useful observations of the tornadic environment. In this case, the radars, one a 3-cm Doppler and the other a 5-cm Doppler, were able to capture the life-cycle of an F1 tornado. The data from both radars were edited to remove problem areas and, with a variety of underlying assumptions, were analyzed to determine if the results were useful. The analysis software provided storm-relative wind vector data and vertical vorticity that, at least qualitatively, agreed with conventional theory regarding the structures of tornadic supercell thunderstorms.

Publications

French, M. M., H. B. Bluestein, D. C. Dowell, L. J. Wicker, M. R. Kramar, and A. L. Pazmany, 2004: Mobile, dual-Doppler analysis of tornadogenesis: The 15 May 2003 supercell in Shamrock, Texas. *Preprints, 22nd Conference on Severe Local Storms*, Oct. 4-8, 2004, Hyannis, MA.
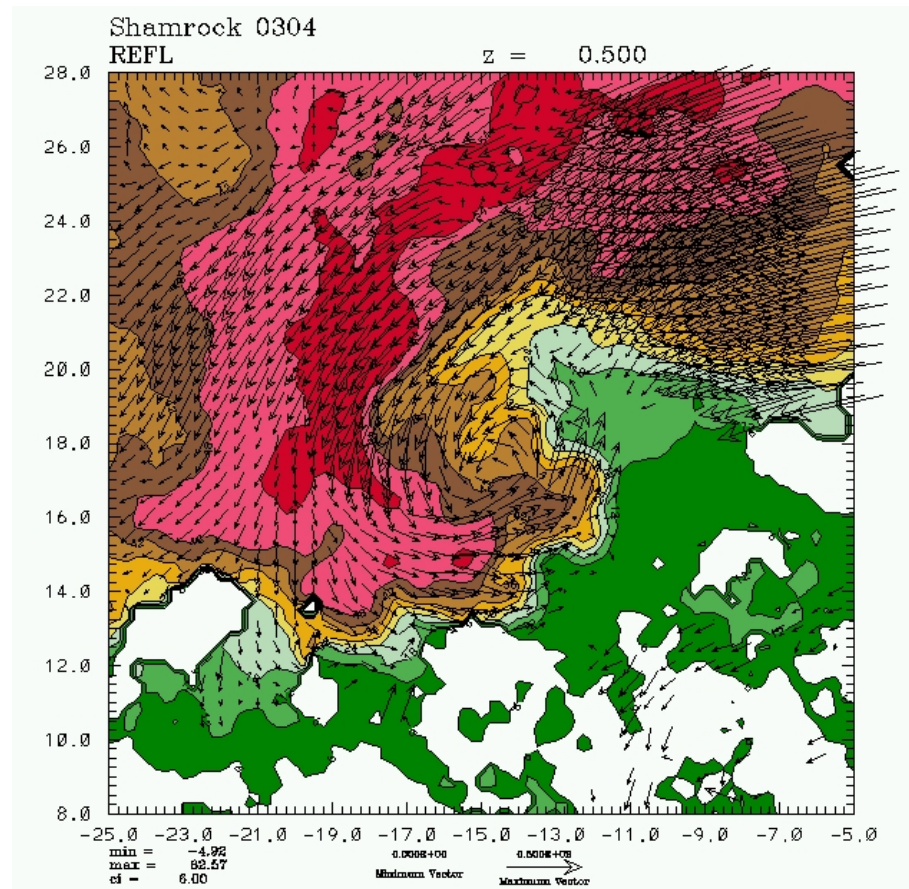
Dual-Doppler analysis showing horizontal, storm-relative wind vectors overlaid on reflectivity factor (dBZ) at 0304 UTC on 16 May 2003. Origin indicates location of SMART radar. Reflectivity factor is contoured every 6 dBZ starting with dark green (white is 0 dBZ). Storm motion was estimated as 12 ms^{-1} from 245 degrees.

Improving Tornado Detection with WSR-88D Data using Spectral Analysis
Yu, **Shapiro**, **Yeary**

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives

Improve tornado detection by identifying vortex signatures in the Doppler spectrum obtained from WSR-88D data.

Accomplishments

This project started on 1 April 2004. Research progress has occurred in the areas of simulation, data analysis, and data collection.

A simulation of tornado spectrum using a Rankine vortex model was completed. Tornado spectra observed by a virtual WSR-88D can be generated over a designated region. The simulation will help us understand tornado spectral signature in a controlled manner. Equivalent Level II data (reflectivity, mean

Doppler velocity, and spectrum width) are estimated and can be compared with vortex signature in the velocity field (strong and localized azimuthal shear). Effects of velocity aliasing and random noise can also be simulated.

We continued analyzing tornado spectrum data collected by KOUN on 8-9 May 2003. Preliminary results, as shown in the figure below, have confirmed that tornado spectrum has a distinct signature that deviates from the conventional Gaussian-like spectrum. We have found that tornado spectrum is flat and broad and the signal-to-noise ratio is significant.

Data from a tornado outbreak on 29 May 2004 in Geary, OK, were collected collaboratively by KOUN, the WSR-88D (KTLX), and the Phased Array Radar (PAR). Time series were recorded in both KOUN and PAR. The Norman Forecast Office has archived the KTLX data (both Level II and III). Evaluation of spectral detection results with operational tornado detection algorithm is in progress.

Publications

Yu, T.-Y., A. Shapiro, D. Zrnic, M. Foster, D. Andra, R. Doviak, and M. Yeary, 2004: Tornado spectral signature observed by WSR-88D, *Preprints, 22nd Conference on Severe Local Storms*, Oct. 4-8, 2004, Hyannis, MA, Amer. Meteor. Soc.

KOUN (el: 0.439°, 5/10/3:43:19 UTC)
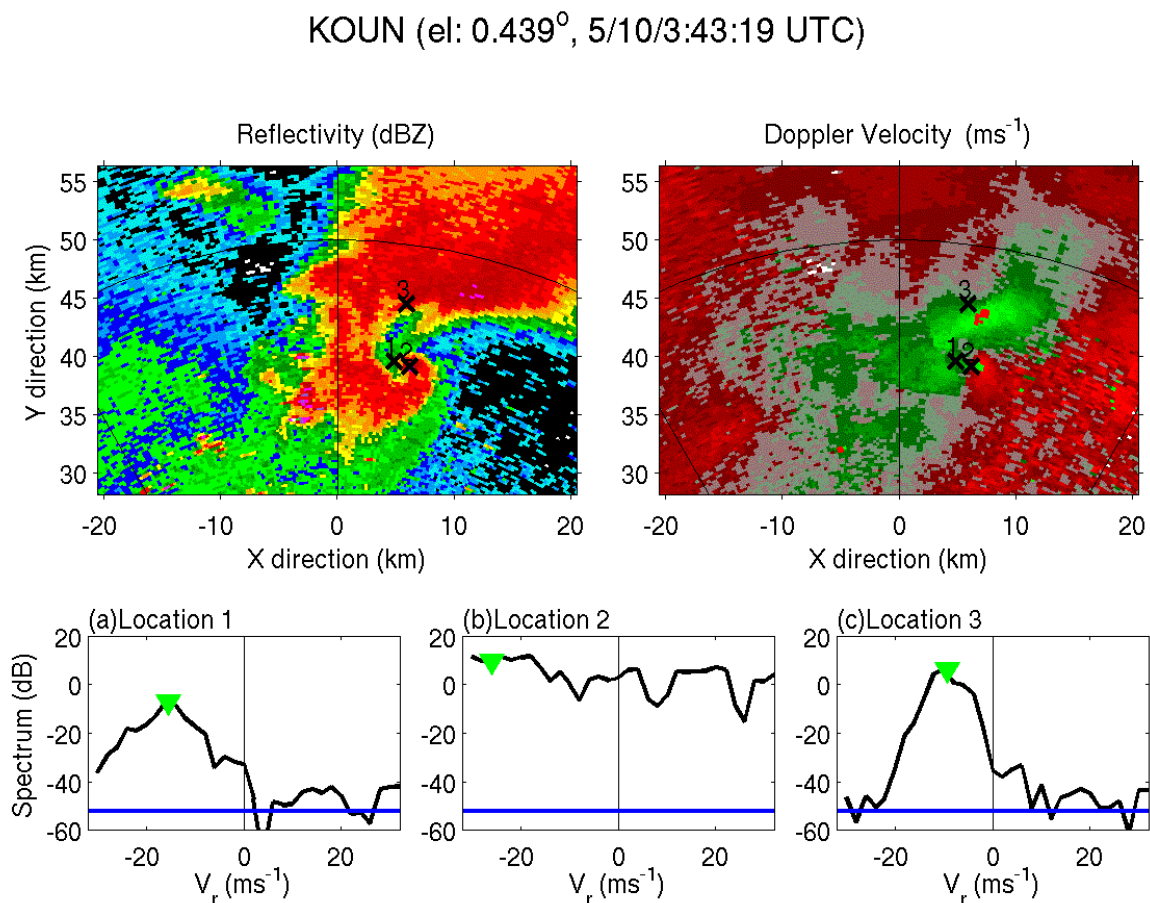
A PPI of reflectivity and mean Doppler velocity are shown in the upper panels for the data collected by KOUN at the elevation of 0.4 degree on 0343 UTC 10 May 2003. A well-defined hook signature and strong azimuthal shear were observed at 6 km east and 39 km north of the radar (labeled 2), suggesting the existence of tornado. Three Doppler spectra in different regions of the flow (labeled 1-3) are denoted by black line in the lower panels. Mean Doppler velocity is denoted by the location of a green arrow. It is evident that the tornado spectrum (location 2) is flattened, while Gaussian-like spectra are observed from non-tornadic regions.

Integrated Radar Data Services (IRaDS)
Martin, Sinclair, **Droegemeier,** and Graduate Research Assistants

NOAA Strategic Goal 3 *(Serve Society's Need for Weather and Water Information)*

Objectives
Provide radar data transmission to the government and private sector.

Accomplishments
IRaDS is a program of the University of Oklahoma developed to provide radar data transmission, at cost. The IRaDS program transitions award-winning Collaborative Radar Acquisition Field Test (CRAFT) research results to a full-time operational service for the public. IRaDS was established as a top-tier source to provision data to the government and private sector. The IRaDS program began April 2004. A NOAA MOA established OU as a top-tier node for Level-II radar on 5 April 2004. To date, staff have established about two-thirds of the desired operational infrastructure. Products have been defined, including bulk weather data and a value-added re-seller approach. A weather technology vendor database has been established containing over 300 prospects. Eight client contracts were established during the program's first four months, with over 20 more prospects showing levels of interest.

Publications
Martin, J. D., and K. K. Droegemeier, 2005: An Internet-based top-tier service for streaming Level II data: CRAFT becomes an operational system. *Preprints, 21st International Conference on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, San Diego, Amer. Meteor. Soc.

The OU/CAPS IRaDS program was established in April 2004. OU/CAPS IRaDS was developed as a program of the University of Oklahoma as a top-tier provider of data transmission, at cost. IRaDS enables private-sector weather commerce with a cost-efficient data collection and dissemination service.

Climate Change Monitoring and Detection

Detection and Attribution of Climate Change Using Climate Indices for the United States
Karoly, Ruppert, **Easterling**, Lawrimore

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Evaluate U.S. climate indices from observational and model data, document the quantitative character of observed climate changes in the U.S. over the last century, and attribute the observed changes to specific climate forcings, where possible.

Accomplishments
This project, which started in May 2004, will use data from coupled ocean-atmosphere climate models to calculate two climate indices for the U.S., the Climate Extremes Index (CEI) and the Greenhouse Climate Response Index (GCRI). These were developed by Karl et al. (1996) to quantify observed changes in climate and climate extremes in the contiguous U.S. The CEI is based on a combination of climate extremes indicators, while the GCRI is a combination of indicators based on projected climate responses due to increasing greenhouse gases. The indices combine changes in climate over several different temperature and precipitation measures and are likely to provide early detection of important changes in climate in the US.

This project will use data from climate model simulations to evaluate the natural variability of these indices and the expected changes of the indices in response to increasing greenhouse gases. Progress in the project so far has included a visit to NCDC for extensive discussions with project partners on the operational code used for calculating the indices at NCDC from observational data. This code is now being converted to use with climate model data. Data from existing simulations with the NCAR Parallel Climate Model (PCM) will be analyzed first. Subsequent analysis will include simulations with the new NCAR and new GFDL coupled ocean-atmosphere climate models that will be included in the IPCC Fourth Assessment Report.

Climate Extremes Index (CEI) for the U.S. from observational data (figure from NCDC web site). The CEI is calculated from observational data for 1948-2003.

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Summer Temperature Extremes in North America East of the Rockies
Rogers, Lamb

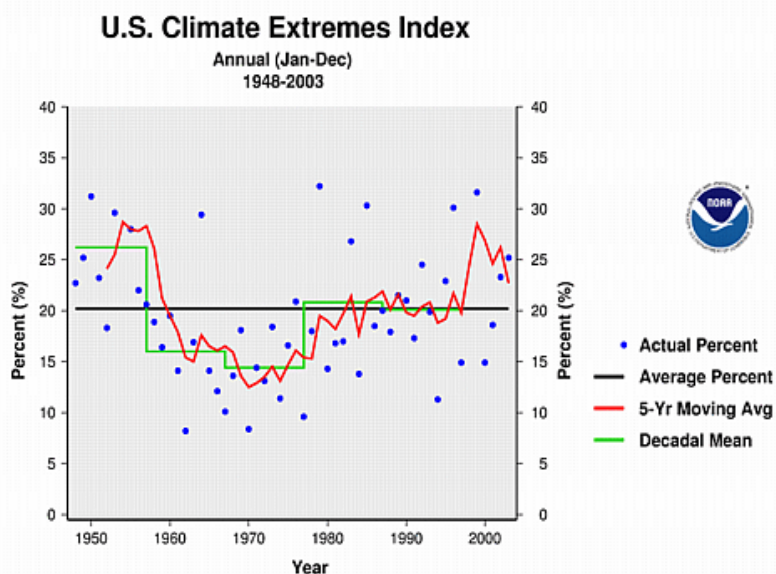**NOAA Strategic Goal 2** *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Determine summertime temperature extremes in North America east of the Rocky Mountains.

Accomplishments
The focus of this investigation is North America east of the Rocky Mountains, using the Lamb/Richman dataset, which consists of 764 grid points in the United States and southern Canada having a 1˚ latitude-longitude spatial resolution. The daily maximum temperatures available in this dataset are analyzed with respect to equatorial Pacific sea-surface temperature, resulting in plots of the difference between El Niño and La Niña years from the overall average year. Both the El Niño/La Niña definition and the analysis periods are the summer months of June through September. Analyses thus far are based on defined extreme thresholds, both absolute (90, 95, 100˚F) and relative (5, 10, 15˚F above/below average).

The most striking results thus far have been with the daily maximum temperature thresholds of 95 and 100˚F. The analyses that are performed look at the number of days per summer and per summer month in which the threshold was met or exceeded in the daily maximum temperature. When considering a 100˚F La Niña anomaly, nearly all of Oklahoma experiences six to eight additional 100-degree days during a La Niña summer, when compared to a 52-year average. Shown below are the individual years that comprise the La Niña composite. The first six of the 11 La Niña years are shown for the 100-degree temperature threshold. While 1956 shows a pattern that is very similar to the composite (not shown), the magnitudes are vastly different. Some years (1950 and 1955) have patterns with opposite sign, while others (1954) are simply larger in area. Currently underway is study to determine if stronger relationships can be established by further grouping the El Niño and La Niña years.

Other patterns are also being investigated, such as 50- and 60-degree daily minimum temperature anomalies in the Midwest and Southern Plains, and above/below average anomalies in the Northeast. In the future, investigation into energy usage or agriculture applications may be done.

100 Degrees (Tmax) : La Nina minus Average (Composite Years)
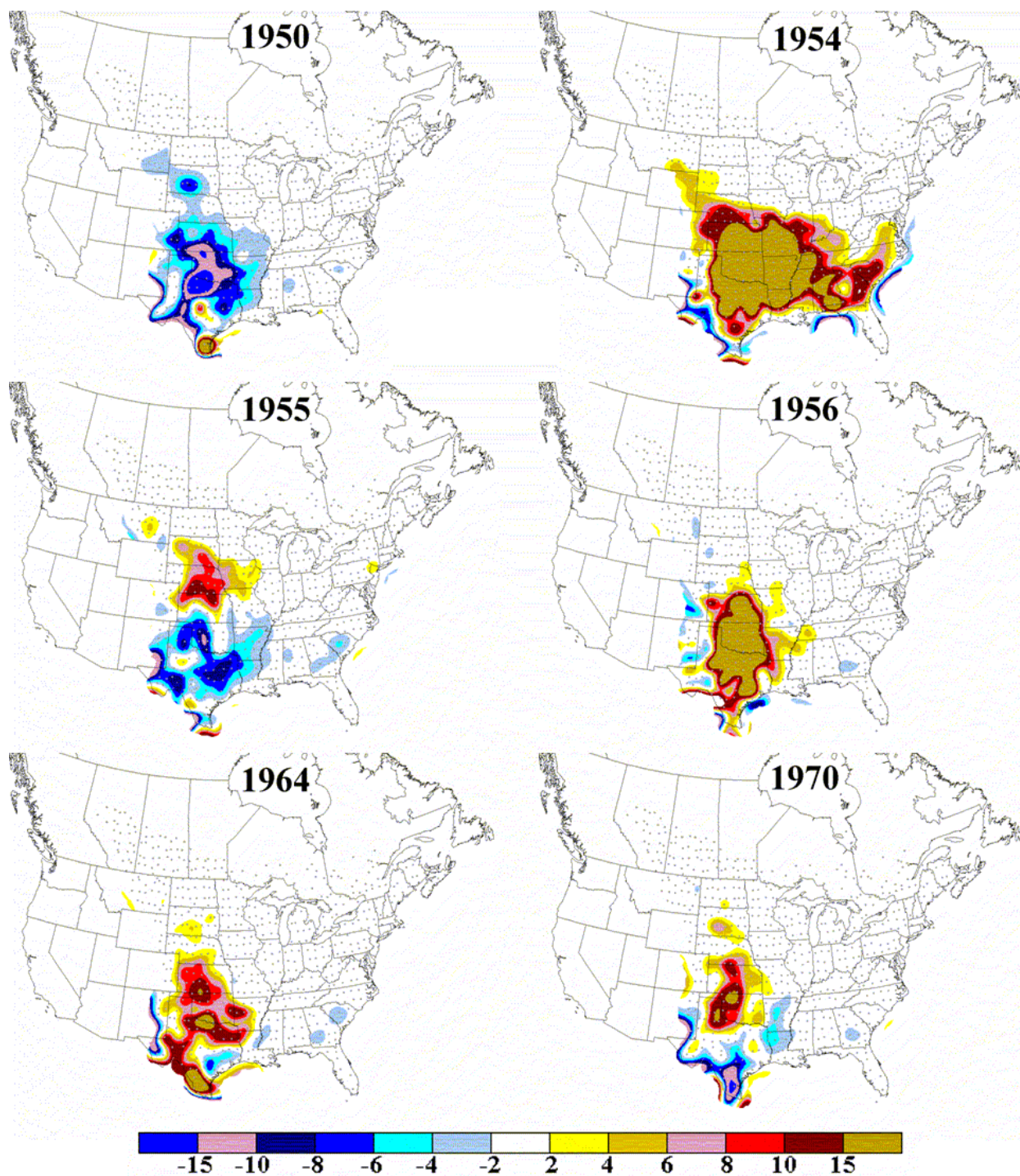
Individual years comprising the La Niña composite for 100-degree days and their deviation from the composite.

North Atlantic Climate Variability
Portis, El Hamly, Lamb

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Investigate the time series behavior of the seasonal signal of the North Atlantic.

Accomplishments
An important issue in studying the climate system is the potential feedback between the atmosphere and the land/ocean/cryosphere. Recently the seasonality of the system has been considered for providing a feedback mechanism for coordination between the low frequency ocean/cryosphere and the high-frequency North Atlantic Oscillation (NAO), a dominant mode of atmospheric variability that significantly affects the regional climate of Europe and Africa and perhaps the global climate through its influence on the thermohaline circulation. Seasonal forcing could precondition, dampen or enhance interactions within the climate system. We have documented the time series behavior of the NAO seasonal signal on different timescales using a mobile NAO index that follows the seasonal migration of the centers of action.

Our results indicate coordination on long time scales between the atmosphere and the ocean/cryosphere. Months with significant signal in the low frequency spectrum had nodal locations over active ocean dynamics (July) and over a region with demonstrated links to low-frequency variations in the SST field (November and February). The phase transition years of the early 1900s and the 1970s in the century-scale wintertime NAO oscillation were accompanied by simultaneous and dramatic changes in other parts of the climate system (sea surface temperature, sea ice extent, sea ice export, salinification of North Atlantic Central water layer) along with a shift in the meridianal position of the NAO nodes. Wavelet analysis showed that these phase transition years were coincident with more active low frequency spectrums for the mobile NAO index.

Publications
Portis, D., M. El Hamly and P. J. Lamb, 2004: Time series behavior of the seasonal signal of the North Atlantic Oscillation. *J. Climate*, submitted.
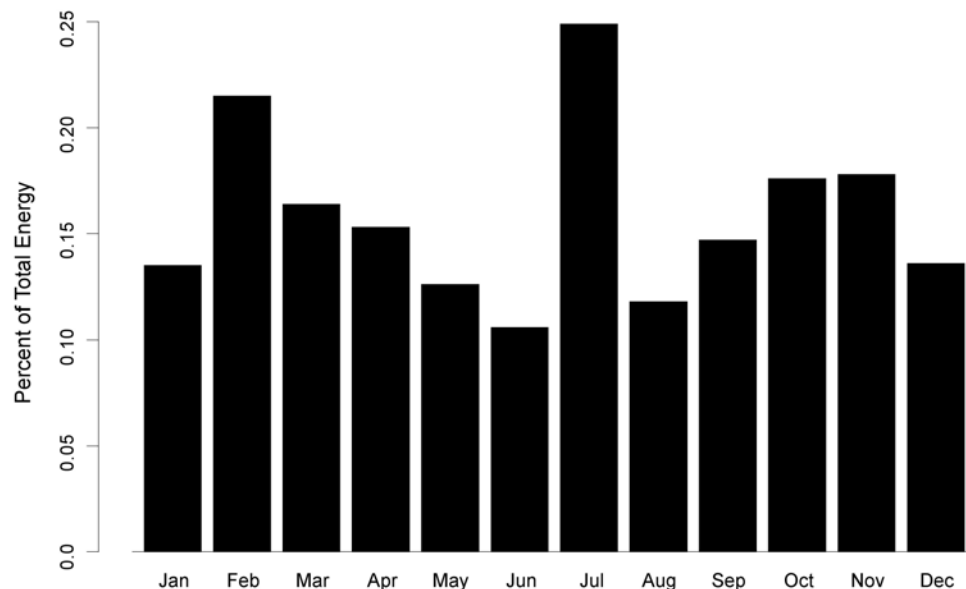
Calendar month estimates of the percentage of total energy that is attributable to the low frequency (> 8 years) spectrum. These calculations are based on a discrete wavelet orthogonal transform of the symmlets type after Daubechies that is applied to each monthly NAOm time series (1873-2000).

Investigation of Long-Term Precipitation Variability across the African Continent
Lamb, Portis, Winstanley

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Investigate the low frequency variability of sub-Saharan precipitation.

Accomplishments
Important issues regarding the variability of sub-Saharan precipitation are 1) the possible existence of a climatic shift in precipitation regimes and 2) the role of other components of the climate system such as the ocean, land, and large-scale circulation patterns (e.g. the North Atlantic Oscillation or the Tropical Multidecadal Mode (Chelliah and Bell, 2004)) in low frequency precipitation variability. We have constructed a considerable observational data set from river discharge time series and by merging station precipitation time series from datasets constructed by Winstanley, Lamb and the USAID Rainman dataset. Before merging the precipitation time series, comparisons were performed by doing a "double mass" analysis during their time of overlap. Recently there has been heightened interest in the stability and causes of sub-Saharan precipitation low frequency variability. Hôte et al. (2002) have identified a climatic shift in Sahelian precipitation in 1969. This is the same year that the North Atlantic Oscillation underwent a phase change for the winter (NDJFM) months. The preliminary figure below shows a ten year filtered time series of precipitation at Banjul, Gambia and the July NAO with a dashed line indicating 1969. Note that after about 1935 there is a negative correlation between the precipitation time series at Banjul and the July NAO.

Ten year filtered time series of precipitation at Banjul, Gambia and the July NAO. The vertical dashed line indicates 1969 that Hôte et al. (2002) have identified as a climatic shift year.

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Sahel Drought Studies
Dai, **Lamb**, Trenberth, Hulme, Jones, Xie

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Analyze rainfall trends in the Sahel to diagnose drought conditions.

Accomplishments
Using station rainfall data extracted from two comprehensive data sets, we show that large decreasing rainfall trends were widespread in the Sahel (10–20 °N and 18 °W–20 °E) from the late 1950s to the late 1980s. Thereafter, Sahel rainfall has recovered somewhat through 2003, although the drought conditions have not ended in the region. These results confirm the findings of many previous studies. We also found that large multi-year oscillations appear to be more frequent and extreme after the late 1980s than previously. Analyses of Sahel regional rainfall time series derived from a fixed subset of stations and from all available stations show that the decreasing trend in Sahel rainfall is not an artifact of changing station networks. The rainfall model used by Chappell and Agnew (2004) is incorrect and their modeled rainfall time series is totally unrepresentative of Sahel average rainfall. Their conclusion about the Sahel rainfall trends being an artifact of changing station locations is emphatically wrong and their speculative statements about the implications of their results for other studies and other regions of the world are completely unfounded.

Publications
Dai, A., P. J. Lamb, K. E. Trenberth, M. Hulme, P. D. Jones, and P. Xie, 2004: The recent Sahel drought is real. *Int. J. Climatol.* **24**: 1323–1331.

ARM Program Data Quality Office
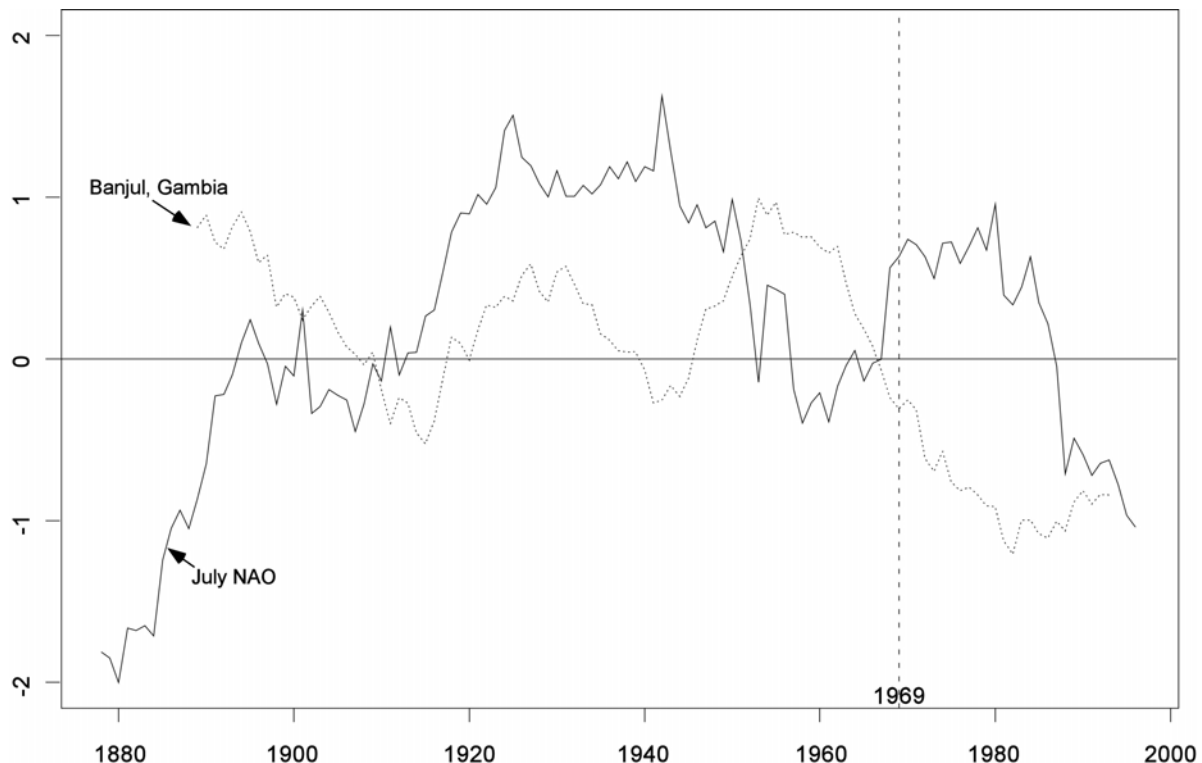**Peppler**, **Sonntag**, **Dean**, **Kehoe**, **Burkholder**, **Shafer, Zaman**, Moore, Bottone, Hughes

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Inspect and assess U.S. DOE ARM data from the Southern Great Plains, Tropical Western Pacific, and North Slope of Alaska sites on a near real-time basis, and provide support to site operators, site scientists, and instrument mentors to solve instrument measurement problems.

Accomplishments
Highlights during the past year included work with ARM Program instrument mentors, site scientists, and site operators to perform data quality assurance tasks and solve instrument performance problems. This was primarily conducted using the Data Quality Health and Status (DQ HandS) tool developed by the Data Quality Office. Improvements were made to the tool, including addition of new instruments and value-added procedures, and development of more streamlined ways to write and submit problem reports. A new diagnostic plot browser was nearing development as well. The Office continued its issuance of weekly synopses of data quality results and problems to ARM site scientists and site operators and weekly individual instrument reports to instrument mentors and site operators. The Office also began issuing monthly compilations of the flagging results of automated quality control checks. Research is ongoing to improve automated flagging techniques and to relate the quality results generated by the creation of value-added products to their input data streams.

Publications
Sonntag, K.L., R.A. Peppler, A.R. Dean, and C.M. Shafer, 2004: How is the Data Quality Office Doing? *Proc., 14th ARM Science Team Meeting*, Albuquerque, NM, U.S. Dept. of Energy.

Mace, G.G., K.L. Sonntag, S. Kato, M. Poellet, C. Twohy, S. Troth, Q. Zhang, and P. Minnis, 2004: The March 2000 Cloud Intensive Observing Period; The Evolution of the Synoptic-Scale Atmosphere and the Associated Cloud Radiative Forcing. *Proc., 14th ARM Science Team Meeting*, Albuquerque, NM, U.S. Dept. of Energy.

Kalb, C.P., A. R. Dean, R. A. Peppler, and K. L. Sonntag, 2004: Intercomparison of Cloud Base Height at the ARM Southern Great Plains Site. *Third Annual Student Conference and Career Fair*, Seattle, WA, Amer. Meteor. Soc.

Peppler, R.A., K.L. Sonntag, A.R. Dean, and C.M. Shafer, 2004: Quality of Atmospheric Radiation Measurement (ARM) Program Data. *Proc., 14th Conf. on Applied Climatology*, Seattle, WA, Amer. Meteor. Soc.
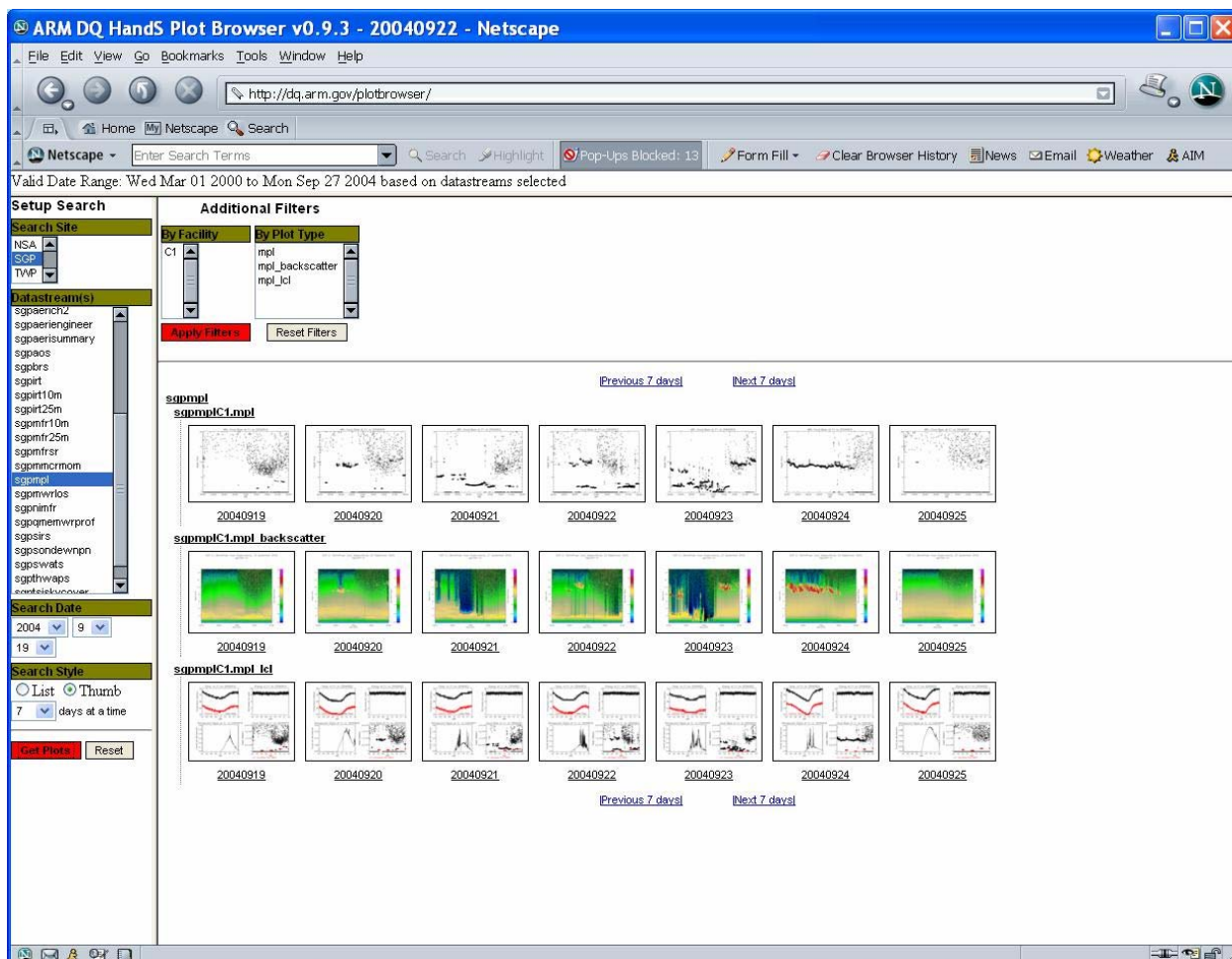
New DQ HandS diagnostic plot browser, showing results for the SGP micropulse lidar during 19-25 September 2004 for variables cloud base height, backscatter, and lidar diagnostics, including a calculated LCL.

ARM Program Southern Great Plains Site Scientist Team
Lamb, Bond, Bahrmann

NOAA Strategic Goal 2 *(Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond)*

Objectives
Provide scientific support for Southern Great Plains site operations, conduct a site-relevant research program, and conduct educational outreach activities.

Accomplishments

The Southern Great Plains Site Scientist Team is responsible for three major areas of activity: provide on-site scientific expertise on a daily basis and support of data quality efforts in coordination with the Data Quality Office; conduct a research program focused on the SGP site data which furthers the goals of the overall ARM Program; and conduct an educational outreach program that exploits the availability of the SGP site and its data streams.

Highlights during the past year included participation in the Continuous Quality Improvement Program (CQIP) during 7-11 July and 17-20 November. The CQIP is comprised of an inspection tour of all SGP extended, intermediate, and boundary facilities to identify safety and data quality issues. Assistance was provided to several field campaigns, including the AIRS Water Vapor Experiment – Ground (AWEX-G) IOP during 27 October – 16 November 2003. Tasks included providing nightly cloud and wind forecasts and constructing a website for updating input by IOP participants. Assistance was also provided to the Midlatitude Cirrus Experiment (MidCiX)/WB-57 Campaign 19 April – 7 May 2004 by providing real-time cloud height reports, switching the Raman lidar cirrus mode to support overflights, and participating in teleconferences as necessary.

Tours were given to: students representing various universities throughout the U.S. during the 2003 NSF Research Experience for Undergraduates program; a National Public Radio reporter; and several university students. Presentations were given on the ARM Program to Kansas and Oklahoma K-12 teachers attending the annual Earthstorm workshop conducted by the Oklahoma Climatological Survey. Staff also served as judges at the OCS's annual Science Fair competition in spring 2004.

Assimilation, Analysis and Dissemination of Pacific Rainfall Data
Morrissey, Postawko, Greene

NOAA Strategic Goal 2 (*Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond*)

Objectives

Enhance the quality and quantity of Pacific rainfall data and help build capacity for the Pacific National Meteorological Services.

Accomplishments

We are expanding our efforts to increase the raingauge climate observing data base representing specific, environmentally critical locations. It is not our intention to collect all raingauge data world-wide, but to assimilate raingauge data 1) in environmentally critical locations (e.g. tropical Pacific), 2) where dense raingauge networks exist, and 3) where agreements can be made to help construct raingauge networks in critical locations. An experimental effort focused on the latter objective with the government of Kiribati has resulted in a network of 15 new raingauges located on 15 atolls managed by the Kiribati Meteorological Service. In addition, similar pilot projects have produced a relatively dense raingauge network on the island of Niue in the south Pacific and a critical all-weather observation platform on Pitcairn island in the southeast Pacific. The success of these relatively low-cost efforts has motivated us to expand these pilot projects to other Pacific Island locales in collaboration with PI-GCOS.

Publications

Grebremichael, M, W. F. Krajewski, M. Morrissey, D. Langerud, G.J. Huffman, and R. Adler, 2003: Error uncertainty analysis of GPCP monthly rainfall products: A data based simulation study, *J. Appl. Meteor.* , **42**, 1837-1848.

Mahmood, R., M. Meo, D. R. Legates, and M.L. Morrissey, 2003: The CERES-rice model-based estimates of potential monsoon season rainfed rice productivity in Bangladesh, *The Professional Geographer*, **55**, 259-273.

Gibson, B.A., S.E. Postawko, J. Ensworth, M.L. Morrissey, J. Wurman, and S. Ellis, 2003: Introducing high-tech and low-tech Geoscience-related technology to disadvantaged schools in the Tropical Pacific. *J. Geoscience Education*, **51**.

Grebremichael, M, W. F. Krajewski, M. Morrissey, G. J. Huffman, and R. Adler, 2003: Detailed evaluation of GPCP one degree-daily rainfall estimates over the Mississippi River basin, *J. Appl. Meteor.*, submitted.

PUBLIC AFFAIRS AND OUTREACH

Oklahoma Weather Center Research Experiences for Undergraduates Program

Zaras, Schultz, Elmore, Spencer, Kain, Baldwin, Lakshmanan, Heinselman, Schuur, Johns**, Scharfenberg, Schlatter, Burgess, Peppler,** Racy**, Shapiro,** Melvin

Objectives

Provide a rich intern experience to ten bright college students from across the U.S. by guiding each of them through a unique research project.

Accomplishments

CIMMS researchers continue to manage, mentor, lecture, and select students who participate in the REU Program at the University of Oklahoma. Ten meteorology, physics, and astronomy college students from across the U.S. participated in the 2004 program. Each student was paired with a CIMMS, OU, or NOAA mentor who guided them through project decision making, writing of a 10-page paper, and presentation of a 15-minute conference-style talk. Lectures, workshops, and field trips supplemented the students' time here to provide an experience much like that of professional scientists. Eight of the ten students were mentored or co-mentored by CIMMS scientists.

The 2004 grant is part of a "Two-Year Extension for Special Creativity" award from the National Science Foundation. Several new items were added to the program, including: 1) send all students to a national conference to present their work and network with the larger atmospheric science community; 2) begin to network students within and across years of the program by organizing an REUnion and creating an REU Directory; 3) bring in two visiting faculty co-mentors in hopes of increasing opportunities for undergraduates to experience research at other institutions; and 4) study how our participants come to clarity on career direction through the experiences in the program.

Publications

Metz, N. D., D. M. Schultz, and R. H. Johns, 2004: Extratropical cyclones with multiple baroclinic zones and their relationship to severe convective storms. *Wea. Forecasting*, accepted.

Hamm, Andrew J., and K. E. Elmore, 2004: A validation of the NCEP SREF. *Preprints, 20th Conference on Weather Analysis and Forecasting*, Amer. Meteor. Soc., Seattle, WA, paper 7.6.

Mazur, R., G. Stumpf, and V. Lakshmanan, 2004: Quality Control of Radar Data to Improve Mesocyclone Detection. *Preprints, 20th Intl Conf on Information Processing*, Amer. Meteor. Soc., Seattle WA, P 1.2a.

Metz, N. D., D. M. Schultz, and R. H. Johns, 2004: Extratropical cyclones with warm-sector baroclinic zones and their relationship to severe weather. *Preprints, 20th Conf. Weather Analysis and Forecasting*, Seattle, WA, Amer. Meteor. Soc.

Charles, M. E., D. L. Andra, D. J. Miller, and M. Foster, 2004: Multiple Radar Comparison and Analysis of the 8 May 2003 Oklahoma City Tornadic Supercell. *3rd Annual Student Conference*, Amer. Meteor. Soc., Seattle, WA, P 1.12

Esker, J., H. Brooks, and M. Baldwin, 2004: Analyzing statistical models of hourly precipitation events. *3rd Annual Student Conference*, Amer. Meteor. Soc., Seattle, WA, P 1.18

Hahnenberger, M., J. Galvez, and M. Douglas, 2004: Summertime precipitation variability and atmospheric circulation over the South American antiplano. *3rd Annual Student Conference*, Amer. Meteor. Soc., Seattle, WA, P 1.21

Hamm, A. J. and K. L. Elmore, 2004: A Validation of the NCEP SREF. *2nd Great Lakes Meteorology Conference,* Northwest Indiana Chapter / National Weather Association, Chesterton, IN.

Kalb, C. P., A. R. Dean, R. A. Peppler, and K. L. Sonntag, 2004: Intercomparison of cloud base height at the ARM Southern Great Plains site. *3rd Annual Student Conference*, Amer. Meteor. Soc., Seattle, WA, P. 1.7

Nestlerode, C. M., and M. B. Richman, 2004: Analysis of the Mesocyclone Detection Algorithm Attributes to Increase Tornado Detection. *3rd Annual Student Conference*, Amer. Meteor. Soc., Seattle, WA, P 1.15.

Potvin, C. K., S. J. Weiss, and S. J. Taylor, 2004: A Study of Proximity Sounding Derived Parameters Associated with Significant Severe Weather. *3rd Annual Student Conference,* Amer. Meteor. Soc., Seattle, WA, P. 1.10

Rapp, D. L., J. B. Basara, and P. K. Hall, 2004: The impact of high wind events on the Central Business District of Oklahoma City. *3rd Annual Student Conference*, Amer. Meteor. Soc., Seattle, WA, P 1.5

REU Class of 2004.

Enlightening Lightning
Mansell

Objectives
Develop a planetarium-based educational program about lightning science and safety.

Accomplishments
This project represents collaboration between OU, Texas A&M University, and Tarleton State University (TX). The "Enlightening Lightning" project goal is to introduce a target audience of 6th-8th graders to lightning research and safety through a planetarium-based presentation at Texas A&M. The show uses a combination of live-action video, slides, digital animation, and narration. Contributions to the project included scientific review and simulated time-lapse cloud animations.

The following article by Amelia Williamson appeared in the 6 November 2003 edition of *The Battalion* at Texas A&M, describing the project:

Enlightening lightning – Texas A&M and Tarleton State researchers to present thunderstorm safety show

Not many people are aware of the science behind lightning and the dangers that lightning poses. For this reason, Richard Orville of the Texas A&M Department of Atmospheric Sciences, ***Edward Mansell, atmospheric scientist and lightning specialist of the Cooperative Institute for Mesoscale Meteorological Studies***, Michael Hibbs, of the Tarleton State University Department of Physics, and Donald House, visualization specialist of the Visualization Laboratory in the College of Architecture at A&M, are teaming up to create a planetarium show for middle school children on thunderstorms, lightning and safety.

The project, Enlightening Lightning, was funded by the National Science Foundation and has been in progress for about a year and a half. In the production of this planetarium show, faculty and students from the fields of atmospheric sciences, physics and visual sciences are working together to apply their research to the education of middle school students. The 40-minute production will not only teach students about the science behind thunderstorms and lightning, it will teach them how to stay safe during a storm.

The show was made in the planetarium format for several reasons.

Orville said a planetarium show will make the students feel like they are right in the middle of a storm and will enhance the way that they learn about science. By making the information exciting, the students will be more interested in the material that is presented and will be able to learn in an interactive way outside the normal classroom setting.

"I think that (the production of the show) is important as an educational project," House said. "We're trying to make science accessible and understandable to young people."

The show is being produced to run as a pilot in the new Tarleton Science Planetarium at Tarleton State in Stephenville, Texas. The show will debut this summer, be evaluated, and may run nationwide soon after, Orville said. There are many planetariums throughout Texas and the United States, so the planetarium format will allow a diverse group of students to view the show.

The producers of the show use many different visualization techniques to convey their messages. The planetarium show uses animation, video, still pictures and simulations.

"We decided that one of the parts of the show should be a video of a family going on a picnic and getting (stuck) in a lightning storm, because that would be a really good vehicle for explaining especially the safety things, but also some of the simpler science things," House said.

The team asked Rebecca Miller, a former A&M student and NBC meteorologist in Fort Worth, to narrate the show. Miller said the production of the planetarium show is important.

"(Children) might not realize how frequently lightning strikes," Miller said. "Hopefully this program will teach them safety."

The group also decided there should be an animated cartoon figure in the show to explain some of the complex scientific processes. Luke Carnevale, an A&M architecture graduate student, is the animator of the show's electron character, Sparky.

Carnevale said Sparky will keep the children interested in the material.

"It takes the monotony out of some guy just narrating," Carnevale said.

House echoed Carnevale's sentiments.

"We needed something fun, a little bit of comic relief, and this guy's electric, he's really jumpy and hyper, and so he creates a little bit of excitement that isn't really in the other parts (of the show)," House said. "He knows everything about electricity, so he's pointing at things that are happening out on the (planetarium) dome."

Another part of the show is the simulation of storms and lightning produced by the digital star projector at the planetarium. The simulations illustrate the scientific processes of the formation of storms and lightning and help the students to visualize the material being presented.

The content of the show focuses on the history of lightning discoveries, the current understanding of lightning formation and lightning safety, Orville said. The bits of science material that are covered in the show teach children how science is applied to things around them in the world.

"(Thunderstorms and lightning are) a common experience that everyone's had, but not everyone's thought about what's really going on," House said. "So (the show) will help (people) understand from the inside out what's going on inside clouds and what lightning and thunder actually are, and how it all works."

An important aspect of the show is the lightning safety tips that it teaches children. Sarah Fowler, an A&M graduate student in the architecture department, is part of the group working on the visualization portion of the project.

"We hope that the people coming to watch (the show) will get a general sense of lightning safety - that's our main concern," Fowler said. "And then they come away with a little of how it works and why it's dangerous in some respects and pretty neat in others."

People do not always realize the dangers that are associated with lightning and storms, Orville said.

"Lightning kills about 100 people in the United States each year and injures between 400 and 500 people," he said. "When lightning strikes the body, it sends the heart into fibrillation and the person will die in five to ten minutes if first aid is not administered immediately."

Orville said he hopes the planetarium show will increase awareness of the dangers of lightning and will help people know what to do if they find themselves stuck in a lightning storm.

"(People viewing the show) will learn to recognize when there is a lightning danger," he said. "They will learn to pay attention to warnings from the National Weather Service and the local television stations."

A&M has a lightning warning system on campus to alert people when there is a high possibility for lightning to strike on or near the campus.

"When there is a high lightning electric field at the earth's surface produced by a nearby thunderstorm, the warning system will sound," said Orville. "A high electric field at the surface (of the earth) frequently precedes a lightning flash to ground."

If a student hears the warning system sound - a horn will blare for about 15 seconds - he should stay away from trees, light poles or high open areas and seek shelter inside a building or car.

Publications

Orville, R., D. House, M. Hibbs, and E. Mansell, 2004: Enlightening Lightning! Coupling Atmospheric Research to K-12 Education Using Planetarium Presentations, *Preprints, 13th Symposium on Education*, Amer. Met. Soc., Seattle, WA.

Shock & Awe – Myth, misconception, fear and fascination spark A&M System collaboration on "Enlightening Lightning!" planetarium project. From *Advance*, April 2004 edition, Office of the Vice President for Research, Texas A&M University, written by Phillip Rollfing.

ARM Program Outreach Activities
Kloesel, Melvin

Objectives
Provide outreach support for the ARM Program to K-12 teachers and students throughout Oklahoma, Kansas, and the U.S.

Accomplishments
ARM Program/SGP educational outreach activities during the fiscal year were marked most notably by the July 2004 EarthStorm workshop for Oklahoma K-12 teachers and the 11th Anniversary Mesonet/ARM Science Fair. ARM/SGP Outreach staff presented papers or posters at the American Meteorological Society Annual Meeting in Seattle, WA; the National Science Teachers Association Regional Meeting in Kansas City, KS; the Oklahoma Science Teachers Association State Meeting in Oklahoma City, OK; and at regional and local teacher in-services and workshops throughout Oklahoma and Kansas.

Another feature accomplishment during the year was Tour Year 1 the "Magic School Bus Kicks up a Storm" traveling children's museum exhibit. The exhibit is a joint effort between the Oklahoma Climatological Survey (OCS) and numerous other entities. ARM data are used heavily in the training of teachers and students so that they may get the most out of their field trip experience. OCS staff trained personnel from 10 children's museums this year, and will do likewise in each of the next four years. Over one million museum customers in six states have visited the exhibit.

For the fifth consecutive year, OCS Outreach presented a workshop for Kansas teachers at Emporia (KS) High School. The workshop provided scientific knowledge to help the Emporia teachers with an online environmental course. The online course provides teachers with increased scientific knowledge, infuses multidisciplinary concepts, promotes integration of technology into classrooms, and encourages teacher networking and peer mentoring. The OCS workshop covered all facets of measurements at the ARM SGP site and the Oklahoma Mesonet, remote sensing, Earth's seasons and its atmosphere, the electromagnetic spectrum, and global warming. Over the past five years, every student (about 2,000) at Emporia High School has worked with ARM data in the classroom.

The ARM/SGP outreach staff and OCS "Storm Team" teacher-consultants traveled throughout Oklahoma and Kansas conducting workshops on how to use ARM and Oklahoma Mesonet data in the classroom. The workshops focused on the OCS Outreach web site and how to use the WxScope Plugin visualization software to display interactive maps and graphs. In addition, a short course entitled "Mirror, Mirror on the Wall, Do Snow and White Reflect It All?" was created and presented at the NSTA meeting in Kansas City, KS, and the 2003 and 2004 EarthStorm workshops in Norman. Evaluations from the teachers taking the short course were unanimously positive. Teachers attending OCS summer programs will reach over 1000 students in their classes this fall.

A notable addition to the suite of workshops sponsored by OCS/ARM SGP Outreach was a workshop for engineering and remote sensing held in Massachusetts for K-12 teachers across North America. This workshop was held at no cost to the ARM program (funded by NSF), yet exposed 25 teachers from across North America to ARM data and OCS on-line lessons that utilize ARM data. These teachers will reach another 1000 students in their schools this fall.

OCS continues work on its Weather Series. The Weather Series is a collection of educational activities intended for use with real-time or archived ARM and Mesonet data. There are two main components of the OCS Weather Series: reference materials and lessons. Teachers use the reference materials as refresher information prior to teaching a given subject. The OCS Weather Series lessons are aimed at the middle school grade level, but can be modified by the teacher to be more or less difficult. The lessons typically require environmental data and many can be used with recent or real-time data. The lessons contain a list of prerequisites for the activity, suggested grade levels, an overview of the lesson content, ideas for the teacher to apply the lesson, the experiment, and several questions. Each lesson is reviewed yearly and new data cases are added. OCS is now expanding these activities to a national focus. A laboratory manual for undergraduate students taking meteorology classes at the University of Oklahoma is currently under development. This lab manual will make extensive use of ARM SGP data.

In addition, newly developed OCS lessons continue to be added to the Aurora Project's GeogWeb site (http://www.auroraok.org). Aurora is a statewide educational project whose mission is to create an interactive collaborative learning community among teachers and students, homes and towns, and public and private organizations across Oklahoma. Aurora uses a geography-based curriculum full of real problems and relevant experiences to integrate several educational disciplines. Learning activities in GeogWeb take advantage of resources in local communities of Oklahoma. Aurora is funded by the U.S. Department of Education.

Outreach Activities of CIMMS Staff at NSSL
Zaras, Rasmussen, R. McPherson, Schultz, Spencer, Scharfenberg, Benner, Manross, Cobb, Burgess

Objectives
Inform an interested public in our research activities and how these activities impact their daily lives; share the task of outreach activities among many staff members, using their skills to best accomplish the task.

Accomplishments
Outreach activities performed during the past year include:

- Erik Rasmussen talked to 5-15 year olds at the Mesa Community Center in Mesa, CO about science and tornado research.
- Renee McPherson mentored a high school student from the Oklahoma School of Science and Mathematics. With colleagues at the Oklahoma Climatological Survey, she is assisting in the preparation of a proposal to bring weather education to American Indian and Hispanic middle school and high school students in Oklahoma.
- Phillip Spencer is an EARTHSTORM mentor for an elementary class in Enid, OK.
- Daphne Zaras attended two career fairs, speaking to over 100 students at the OU School of Meteorology and about 1000 students at the Moore-Norman Technology Center. She also spoke to an adult learning class about the challenge of educating the public about the hazards of taking shelter under highway overpasses during tornadoes. She served on the core committee to create a Severe Weather Poster highlighting NOAA's work in the areas of hurricanes, tornadoes, lightning, and flooding. Approximately 15,000 middle school science teachers nationwide received this poster in the spring issue of the National Science Teachers Association magazine. She is working with a Norman High School student who is interested in learning about careers in meteorology. She spoke with several hundred Air Force personnel at the 552nd Wing Safety Fair at Tinker Air Force Base and talked about weather with 30 science and math teachers from across Oklahoma. She works with a few high school students and adults who do volunteer work at NSSL. In the past year, she has also spoken to various groups and individuals (total 345) about Lab activities, answered 218 telephone queries, and responded to 553 e-mail letters as the NSSL webmaster.
- Dave Schultz mentored an Ohio high school student on his science fair project, for which the student was selected as a finalist in the national Intel Science Search. He co-mentored a college student during the summer as part of the NSF-sponsored Research Experience for Undergraduates (REU) program at the lab and gave presentations on good scientific communication to participants in the program. He also met with several undergraduate students from SUNY Albany and discussed careers in meteorology with them. He spoke to an OU Senior Capstone class about writing and speaking skills and to the OU student chapter of the AMS about his experience leading a research field program. He spoke to Leadership Norman about life as a research meteorologist. He co-advises two OU M.S. students, serves on the committee of another M.S. student, and advises two undergraduate students in their research. He gave six high school students and their parents tours of NSSL. He spoke to an ABC News reporter about lightning in winter storms. He also writes the Weather Watch column, that highlights NOAA and NSSL research, for Canoe & Kayak magazine.
- Kevin Scharfenberg talked about weather to a second grade class at an elementary school in Sherwood, AR and made a presentation to the joint Arkansas chapter of the American Meteorological Society (AMS) and National Weather Association (NWA). He also gave tours of NSSL to members of a meteorology class at OU and to a prospective OU undergraduate student.
- Mark Benner periodically checks on the operation of NOAA weather radios that the employees association gave to eight local elementary schools.
- Susan Cobb served as a judge for the Homeschool Science Fair. She also talked about severe weather with a 4th grade class at Roosevelt Elementary School in Norman.

- Kevin Manross talked with a 4th grade class in Midwest City about weather, weather safety, and storm chasing.
- Don Burgess served as a judge at the Oklahoma State Science Fair. He provided teaching material and background weather information to two elementary school teachers in Texas. He also spoke to a group of high school students visiting from Minnesota.

Outreach Activities of CIMMS Staff at WDTB
Morris, Schlatter, Yu

Objectives
Develop simulation capabilities to enhance warning decision making research and training.

Accomplishments
Outreach activities conducted during the fiscal year include:

- Served as mentors for two groups of OU students for their research project, aiding them in generating Workstation Eta model output and WSR-88D radar product data as part of their respective projects.
- Mentored an REU student during summer 2004
- Participated in the OK-FIRST Assistant's Workshop in Stillwater
- Participated in the Outdoor Classroom for Deer Creek Conservation District in Weatherford (~200 4th graders from area school districts)
- Gave a speech to the OU Club of Tulsa on usage of meteorological radar data by non-meteorologists

Appendix A

<u>CIMMS AWARDS AND HONORS</u>

Gourley (NSSL)

- <u>Universities Council on Water Resources Dissertation Awards Committee 2004</u>: Honorable Mention

Hoggard, Magsig, Mohamad Said, Wood, Yu (WDTB) and Stumpf, Smith, Manross, Lakshmanan, Scharfenberg, Elmore, Song, Toomey, Cooper, Hondl**, Brogden, Kerr, Hocker, Ortega, Adams (NSSL)**

- <u>U.S. Department of Commerce NWS Bronze Medal 2003</u>: With NWS colleagues at WDTB, ROC, Space Flight Meteorology Group, Southern Region Headquarters, NSSL, and NCDC, "for rapid and innovative actions in collecting, archiving and analyzing weather radar data to assist the Shuttle Columbia accident investigation."

Howard**, Arthur, Cox (NSSL)**

- <u>U.S. Department of Commerce NWS Bronze Medal 2003</u>: "for the development and operational implementation of the Flash Flood Monitoring and Prediction System."

Magsig, Yu (WDTB)

- <u>National Weather Association (NWA) Larry R Johnson Special Award</u> (with John Ferree, Ed Mahoney, Ed Berkowitz, Ronald Guenther, and Debra McManes), for their work on the Archive IV to Weather Event Simulator project. This award is presented to an individual or a group "to recognize unique events or extraordinary accomplishments, which significantly contributed to operational meteorology."

Schultz (NSSL)

- Selected as an <u>Editor</u> for *Monthly Weather Review*

Stumpf, Smith, Manross, Lakshmanan, Scharfenberg, Elmore, Song, Toomey, Benner, Cooper, Hondl**, Brogden, Kerr, Hocker, Ortega, Adams, Gourley, J. Zhang, Arthur, Clarke, Cox, Langston, Qin, Wang, Xia, Farmer, Donner (NSSL)**, along with ROC, NSSL, and NWS Federal collaborators

- <u>NOAATECH Award 2004</u>: Best Presentation for "Real-time Dissemination of WSR-88 Radar Data over Internet2". The National Oceanic and Atmospheric Administration awarded the team behind a collaborative project to make high-resolution weather radar data available in real-time to the public its prestigious 2004 Technology Transfer Award. The award recognized the team "for development of a national real-time radar data archival and Internet2 delivery system for university, government and private sectors." Taking advantage of high performance networking capabilities and other recent technological advances, the team successfully transferred the technology from research into NOAA's National Weather Service, private sector operations and research and education facilities.

Zaras (NSSL)

<u>"Two-Year Extension for Special Creativity"</u>: National Science Foundation, extending the Research Experience for Undergraduates award for an additional two years, into 2006.

Appendix B

PUBLICATION SUMMARY

	CIMMS Lead Author			NOAA Lead Author			Other Lead Author		
	FY02	FY03	FY04	FY02	FY03	FY04	FY02	FY03	FY04
Peer Reviewed	26	24	34	7	12	10	18	19	20
Non-Peer Reviewed	37	52	51	7	17	9	11	21	7

FY04 Summary			
Author	**Peer Reviewed**	**Non-Peer Reviewed**	**Total**
CIMMS Lead Author	34	51	85
NOAA Lead Author	10	9	19
Other Lead Author	20	7	27
Total	**64**	**67**	**131**
Theses	**4** (2 Ph.D., 2 M.S.)		

(Publications listed in this document as "submitted" were not included in the above summary)

Appendix C

PERSONNEL SUMMARY

NOAA Funded Research

Category	Number	B.S.	M.S.	Ph.D.
Research Scientist	38		21	17
Visiting Scientist	4		1	3
Postdoctoral Fellow	0			
Research Support Staff	23	8	11	
Administrative	4	2		1
Undergraduate Students	17			
Graduate Students	9	5	4	
Total	**95**	**15**	**37**	**21**
Located at NOAA Unit	SPC-1; SRH-1; ROC-3; WDTB-9; NSSL-75			
Obtained NOAA employment within past year	1			

Non-NOAA funded Research

Category	Number	B.S.	M.S.	Ph.D.
Research Scientist	15		9	6
Visiting Scientist	2		2	
Postdoctoral Fellow	1			1
Research Support Staff	1			1
Administrative	2		1	1
Undergraduate Students	8			
Graduate Students	21	15	6	
Total	**50**	**15**	**18**	**9**